NOYES KNEE INSTITUTE

STRESS FRACTURES, BONE BRUISES, AND SHIN SPLINTS: EVERYTHING YOU NEED TO KNOW TO MAKE THE RIGHT TREATMENT DECISION

- HAIRLINE, FATIGUE, INSUFFICIENCY FRACTURES
- MEDIAL TIBIAL STRESS SYNDROME
- DIAGNOSIS
- TREATMENT
- PREVENTION

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WRITTEN BY AN INTERNATIONALLY RECOGNIZED ORTHOPAEDIC SURGEON AND A CLINICAL RESEARCHER WITH DECADES OF EXPERIENCE IN TREATING PATIENTS WITH KNEE PROBLEMS

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About the Authors

Dr. Frank Noyes is an internationally recognized orthopaedic surgeon and researcher who has specialized in the treatment of knee injuries and disorders for nearly 4 decades. He is the founder and chairman of the Cincinnati SportsMedicine and Orthopaedic Center and its nonprofit research foundation. Dr. Noyes completed his orthopaedic training at the University of Michigan Medical Center. He then received a 4-year clinical and research appointment as an orthopaedic surgeon in the United States Air Force, was commissioned as a Lieutenant Colonel, and began his landmark research into knee ligament injuries, the effects of immobilization, biomechanics of ligaments, prevention of ACL injuries in the female athlete, the diagnosis of many knee injuries and problems, and the results of treatment for a variety of knee disorders. Along with Dr. Edward Grood, Dr. Noyes established one of the first biomechanics laboratories in the United States at the University of Cincinnati College of Engineering. The laboratory was subsequently named in his honor as the Noyes Tissue Engineering and Biomechanics Laboratory.

Dr. Noyes has won every conceivable award for his clinical and laboratory research from societies such as the American Academy of Orthopaedic Surgeons, the American Orthopaedic Society of Sports Medicine, the Orthopaedic Research and Education Foundation, as well as the University of Cincinnati. He was inducted into the American Orthopaedic Society for Sports Medicine's Hall of Fame in 2008. Dr. Noyes has been selected by his peers as one of the Best Doctors in America every year since 1992.

Dr. Noyes has published over 260 clinical and scientific research studies and textbook chapters. These publications detailed surgical techniques and clinical outcomes on many different types of knee injuries and disorders. He edited a textbook entitled, "Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes" which was written for orthopaedic surgeons, physical therapists, and other sports medicine health care professionals. Dr. Noyes is also a co-editor of "ACL Injuries in the Female Athlete. Causes, Impacts, and Conditioning Programs", a textbook written for sports medicine health care professionals, coaches, and trainers involved with female athletes.

Sue Barber-Westin has directed clinical research studies for Dr. Noyes' research Foundation for nearly 3 decades. In the mid 1980's, she authored one of the first studies that measured problems during single-leg hopping tests in patients with ACL injuries, "Quantitative Assessment of Functional Limitations in Normal and Anterior Cruciate Ligament-Deficient Knees." She has co-authored 140 articles in medical journals and textbooks, focusing on the clinical outcome of various knee operative procedures, the methods used to determine the results of clinical investigations, differences in neuromuscular indices between male and female athletes, effects of neuromuscular training in female athletes, and prevention of ACL injuries in female athletes. Sue is the associate editor of "Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes" and is the co-editor for "ACL Injuries in the Female Athlete. Causes, Impacts, and Conditioning Programs". Sue has personally undergone 4 knee operations and played competitive junior and collegiate tennis.

In 2004, Sue and Dr. Noyes were members of the clinical research team that won the Clinical Research Award from the Orthopaedic Research and Education Foundation. They are frequently invited to speak at national and international conferences and review articles for orthopaedic and sports medicine journals. Noyes and Barber-Westin have written several other eBooks for patients:

1. ACL Injury: Everything You Need to Know to Make the Right Treatment Decision

2. ACL Injury Rehabilitation: Everything You Need to Know to Restore Knee Function and Return to Activity

3. Knee Meniscus (Cartilage) Tears: Everything You Need to Know to Make the Right Treatment Decision

4. Patellar (Kneecap) Pain and Problems: Everything You Need to Know to Make the Right Treatment Decision

5. Operations for Knee Arthritis: What To Do When All Else Has Failed To Stop Your Knee Pain

6. Knee Arthrofibrosis: Everything You Need to Know to Recognize, Treat, and Prevent Loss of Knee Motion After Injury or Surgery

7. Partial Knee Replacement: Everything You Need to Know to Make the Right Treatment Decision

8. PCL and Posterolateral Knee Ligament Injuries: Everything You Need to Know to Make the Right Treatment Decision

9. The Unstable Patella (Kneecap): Everything You Need to Know to Make the Right Treatment Decision

10. Bowed Leg (Varus) and Knock-Knee (Valgus) Malalignment: Everything You Need to Know to Make the Right Treatment Decision

Introduction

There are many different types of injuries that can happen to bones in the human body. A fracture represents a complete break in which the pieces of bone completely separate. This injury may occur as a result of direct trauma to the bone, or from other factors such as advanced age or a metabolic bone disease such as osteoporosis. However, there are other bone injuries that can be just as problematic (or even more so), such as stress fractures, insufficiency fractures, bone bruises, and shin splints. Although these types of bone injuries do not represent a complete break of a bone, they can cause pain for many weeks or even many months and can interrupt all types of activities. These injuries can be difficult to diagnose and magnetic resonance imaging (MRI) is usually required to determine the source of pain and magnitude of the problem.

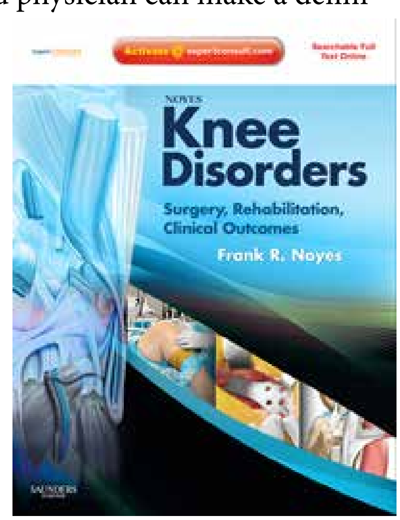
Most stress fractures and shin splints are associated with sports and military training. A sudden or rapid increase in training frequency, intensity and/or duration, or a change in the training surface are well-known causes of these injuries. This represents the "too much, too fast" training regimen in which errors may occur from poor technique and/or fatigue. These problems occur in patients with normal bone.

In contrast, insufficiency fractures occur in bones that are abnormally weak due to a disease such as osteoporosis or other conditions that changed the normal strength and mineral content of the bone. These types of fractures, which are actually small cracks, occur with just normal loads placed on bone. It is important to diagnose and treat these injuries because, if left untreated, they may progress to a complete fracture or not completely heal.

Bone bruises usually occur from a traumatic injury and frequently accompany another major problem such as a knee ligament tear or dislocated kneecap. They can only be detected on MRI and can be painful for a long period of time. The majority of anterior cruciate ligament tears are accompanied by bone bruises and, although the bruises vary in size and severity, they may hinder the normal healing and recovery process. Bone bruises may also occur as a result of a direct blow to a bone, such as a kneecap hitting the dashboard in a car accident.

After treating patients for nearly 4 decades with stress fractures, insufficiency fractures, bone bruises, and shin splints, we decided to write this eBook to try to help individuals understand these injuries and how they should be treated. This eBook provides information on basic anatomy and function of bones, what causes bone injuries and where they occur, how they are diagnosed and treated, potential problems that may happen if they are left untreated, and tips for prevention.

This eBook should not be used for self-diagnosis and treatment of stress fractures, insufficiency fractures, bone bruises, and shin splints. Only a qualified orthopedist or sports medicine-trained physician can make a definitive diagnosis of these problem. For medical professionals, we recommend our textbook "Noyes' Knee Disorders. Surgery, Rehabilitation, Clinical Outcomes" for more comprehensive information regarding the diagnosis and treatment of knee injuries and problems including ligament tears, patellofemoral problems, preventing knee ligament injuries in the female athlete, meniscus injuries, and cartilage restoration procedures.



All About Bones

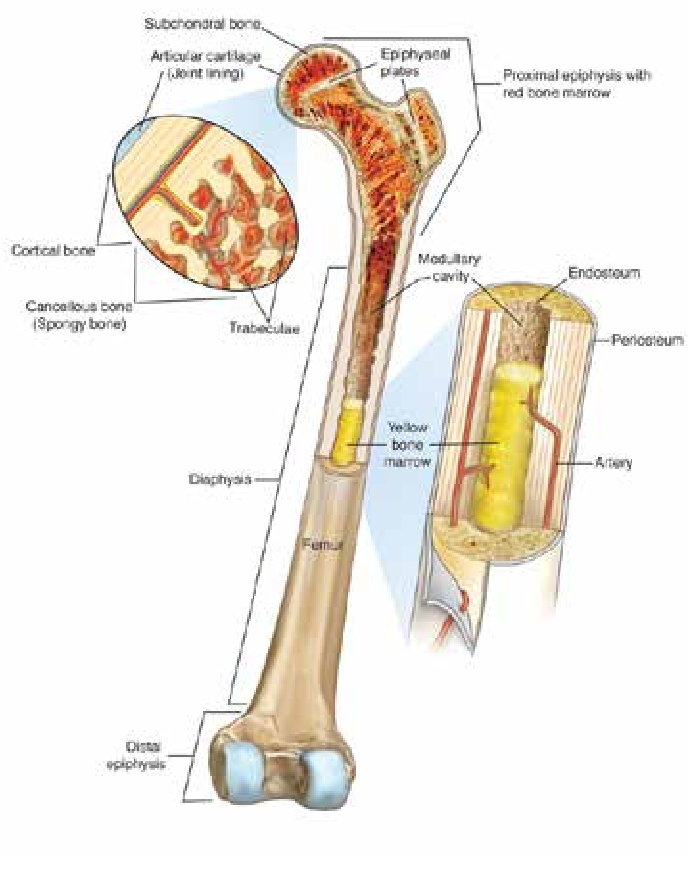
A basic understanding of what bones do, how they function, and their basic anatomy is helpful to be able to comprehend the injuries discussed in this eBook; namely, stress fractures, insufficiency fractures, bone bruises, and shin splints. Bones are rigid organs that support and protect various parts of the body, allow locomotion, help with breathing, produce blood cells, and store essential minerals such as calcium and phosphorus. There are 4 general types of bones: long, short, flat, and irregular.

Bones are made up of different types of tissue including red and yellow marrow, endosteum, periosteum, nerves, blood vessels, and cartilage.

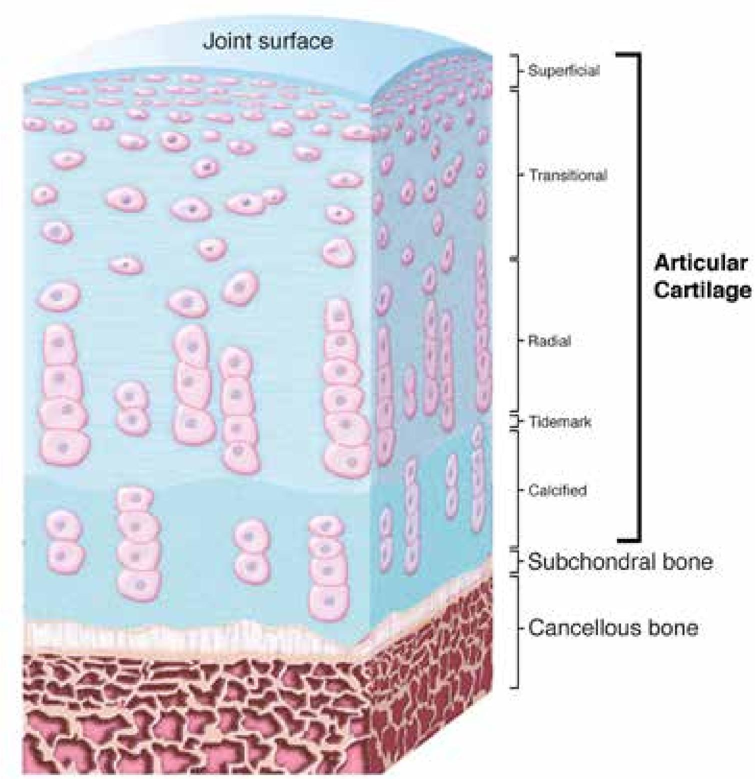
The long bones have a hollow shaft, called the *diaphysis*. The inner space within the shaft is called the *medullary cavity*. Yellow marrow is found within this cavity. At each end of long bones are 2 *epiphyses* which contain red bone marrow, which is responsible for the production of red and white blood cells and platelets.

The diaphysis is mostly composed of dense, compact *cortical* bone. Cortical bone surrounds the marrow cavities. The epiphyses are composed of "spongy" or *cancellous* bone. Cancellous bone comprises a network of trabeculae, has many large spaces that gives it a honeycombed appearance, and encloses areas that contain yellow marrow.

Bones are covered by 2 membranes: the *periosteum*, located on the outside of the bone, and the *endosteum*, which lines the medullary cavity. The periosteum is a thick, fibrous tissue sheath that surrounds the cortical surface of bone, except at the joints where bone is covered by articular cartilage. Underneath the periosteum lie tunnels and canals through which blood and lymphatic vessels run to carry nourishment for the bone. Some muscles, ligaments, and tendons attach to the periosteum, which we will discuss in the section on Shin Splints later in this eBook.



The ends of long bones are covered with *subchondral bone*, which in turn is covered with *articular cartilage*. Articular cartilage is often referred to as the "joint lining". This vital tissue helps joints move and protects the underlying subchondral and cancellous bone from an abnormal amount of stress. The loss or degeneration of articular cartilage is better known as osteoarthritis.



Structures located at the end of a long bone. Cancellous bone (located on the epiphyses) is shown on the bottom, followed by subchondral bone, and then articular cartilage. There are 5 layers of cartilage, each of which has different alignment, number, size, and shape of cells called chondrocytes (illustrated in pink).

Bones constantly remodel and repair themselves, especially when subjected to tremendous stress or an increase in loads. This is done to maintain healthy bone and keep it from weakening. There are two main types of bone cells responsible for this process; one type helps form new bone tissue, while another type breaks down and helps the body absorb older bone tissue:

Osteoblasts, found within the deeper layer of periosteum and endosteum, are responsible for forming new bone tissue

Ostoclasts, located in bone marrow and throughout the bone, are responsible for removing or absorbing bone tissue

Normally, bone that is under a high amount of stress will remodel itself over time in order to become stronger. Bone is deposited in areas subjected to stress and is reabsorbed from areas where there is little stress. These events may change the shape or density of the bone. This process, known as Wolff's law, takes time and if the stress is excessive and repetitive (thereby producing a greater amount of force than a bone normally bears), the normal remodelling procedure is disrupted. In contrast, if bone does not receive a certain amount of mechanical stress, it will weaken or loose its normal amount of mass. Bones therefore react to stress and loads by getting bigger or smaller, stronger or weaker.

Stress Fractures

What is a Stress Fracture?

A stress fracture - also sometimes called a hairline fracture, fatigue fracture, subtle fracture, or low-trauma fracture - is a small crack or cracks in a bone caused by unusual or repeated stress, or heavy continuous weight that is placed on an ankle or leg. This problem occurs in bones that are otherwise normal and not weakened or softened by a disease such as osteoporosis. A stress fracture is different from other types of fractures that occur from a traumatic event or sudden force. Most stress fractures are associated with sports and military training. A sudden or rapid increase in training frequency, intensity and/or duration, or a change in the training surface are well-known causes of this injury.

There are other terms used to indicate small cracks in bone, including insufficiency fracture, osteoporotic fracture, and incremental fracture. The difference between these injuries and a stress fracture is that an insufficiency or osteoporotic fracture results from a normal or small amount of stress placed on a bone that is abnormally weak from a disease such as osteoporosis. An incremental fracture refers to an abnormality caused by Paget's disease, a chronic disorder that weakens bones.

How Stress Fractures Happen

The sequence of events that may lead to a stress fracture begins with increased osteoclastic activity (removal and absorption of bone tissue by osteoclast cells) in response to an abnormal amount of repetitive stress or loads. The removal of bone tissue surpasses the formation of new bone tissue. Thus, an imbalance exists between the normal formation and resorption of bone. This temporarily weakens the bone and produces what is termed bone tissue fatigue.

With continued repetitive stress, microfractures (tiny cracks) appear which are accompanied by bone marrow edema. Bone marrow edema is inflammation that causes too much fluid in the bone and is usually associated with bone injuries and disorders. This stage in the sequence of events is called "stress reaction" or "stress response" and is viewed by physicians as a prelude to a stress fracture. If left undetected or untreated, the damage will progress to the outer surface of the bone, creating a true stress fracture.

Here is a MRI showing a stress fracture of the tibia (below yellow lines).

The final sequence of events is progression to a complete fracture which goes all the way through the bone.

Muscle fatigue also plays a role in this process. Normally, muscles (and other soft tissues) help absorb shock. When muscles are fatigued, certain areas of bones must absorb more shock than what they are normally accustomed to, which can lead to a stress fracture.

Where Stress Fracture Occur

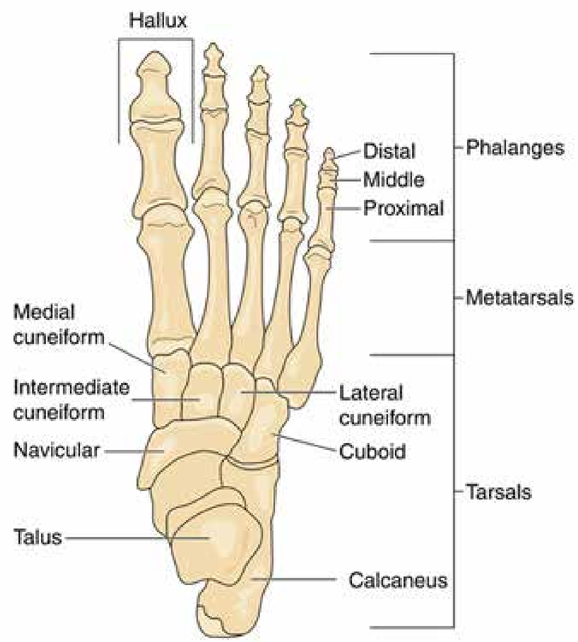
The majority of stress fractures (90%) occur in the weight-bearing *lower extremity*, especially in the foot and leg. Athletes of all types (especially long-distance runners, basketball players, tennis players, gymnastics, and ballet dancers) and military recruits are the most frequently treated patients with this injury.

Foot/Ankle
Metatarsals (bones in the feet; 2nd and 3rd metatarsals most common sites)
- Runners, military training, ballet dancers, hikers, tennis players, basketball players

Calcaneus (heel bone)
- Common site in all populations

Navicular (midfoot)
- Runners, basketball players, rugby players, tennis players

Talus (ankle)
- Rarely reported

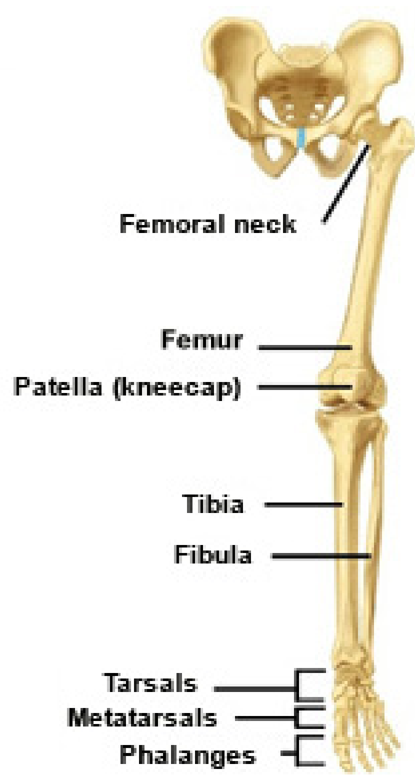


Leg
Femur (thigh bone)
- More common in female athletes than male athletes; femoral neck stress fracture associated with female athlete triad
- Long distance runners, military training

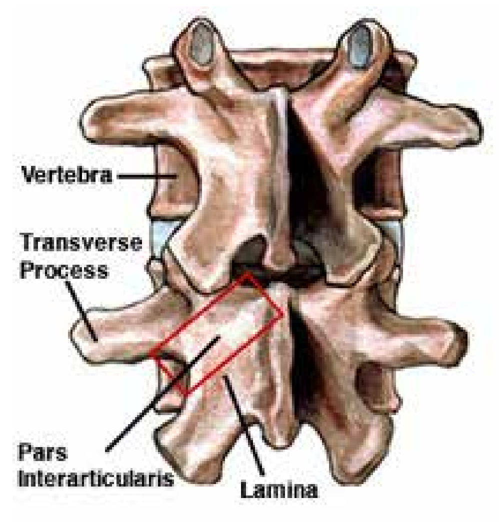
Tibia (shin bone; lower two-thirds of tibia most common area) and fibula (small bone that lies parallel to tibia; just above the ankle most common area)
- Runners, ballet dancers, tennis players

Hip/Pelvis
Sacrum:
- Long-distance runners, may be associated with female athlete triad

Pubic rami:
- Long distance runners, Australian football players, military training, gymnasts, dancers, soccer players



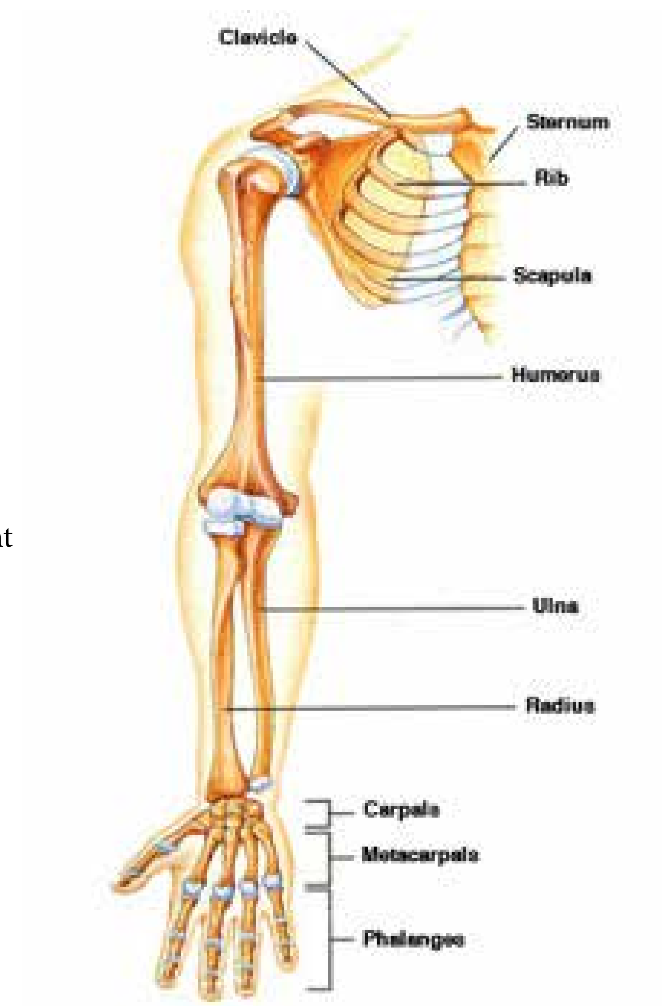
Although more rare, stress fractures may occur in the upper extremity as a result of repetitive loading where a muscle attaches to bone, or heavy repetitive impact loading in upper extremity weight-bearing athletes such as gymnasts, divers, and cheerleaders.



Spine
Pars interarticularis (small connecting bone in lumbar spine)
- Gymnasts, football players, martial arts athletes, weight lifters, tennis players

Chest area
Ribs
- Gymnasts, swimmers, rowers, golfers, rugby players, volleyball players, tennis players, basketball players, soccer, wind surfers, hikers with backpacks

Scapula (shoulder blade)
- Gymnasts, American football, running with hand-held weights



Sternum (breastbone)
- Wrestlers, golfers

Clavicle (collarbone)
- Javelin throwers, rowers, gymnasts, divers, weight lifters

Arm/Elbow/Hands
Humerus (arm bone from shoulder to elbow)
- Baseball pitchers, tennis players, javelin throwers, weight lifters

Olecranon (elbow)
- Throwing sports, racquet sports, volleyball players, weight lifters

Ulna and radius (forearm bones)
- Baseball and softball pitchers, tennis players, volleyball players, weight lifters, bowlers, golfer, polo players, gymnasts, cyclist, badminton players

Metacarpals, phalanges (hand bones)
- Isolated case reports in a softball pitcher, tennis players, rower, climber

Risk Factors

There are internal (intrinsic) and external (extrinsic) factors that may increase the risk of a stress fracture.

Intrinsic factors:
- Body's healing capabilities
- Menstrual patterns
- Level of fitness
- Body mass index
- Muscle strength and endurance
- Anatomic alignment
- Microscopic bone structure
- Bone vascularity (blood supply)
- Gender (female)

Extrinsic risk factors:
- Training program
- Playing/training surface
- Diet
- Athletic equipment, shoes
- Trauma, injury

The most common risk or cause of stress fractures is a sudden or rapid increase in training frequency, intensity and/or duration. A change in the training surface is another well-known cause. In addition, going from a sedentary lifestyle to active training without appropriate periodization may cause a stress fracture. It is generally believed that the initiation of a more intense training program requires a graduated increase over 6 weeks to allow the body to adapt.

Certain occupations may increase the risk of a stress fracture. For instance, a jackhammer/pneumatic drill operator may suffer this injury to a metacarpal (hand) bone.

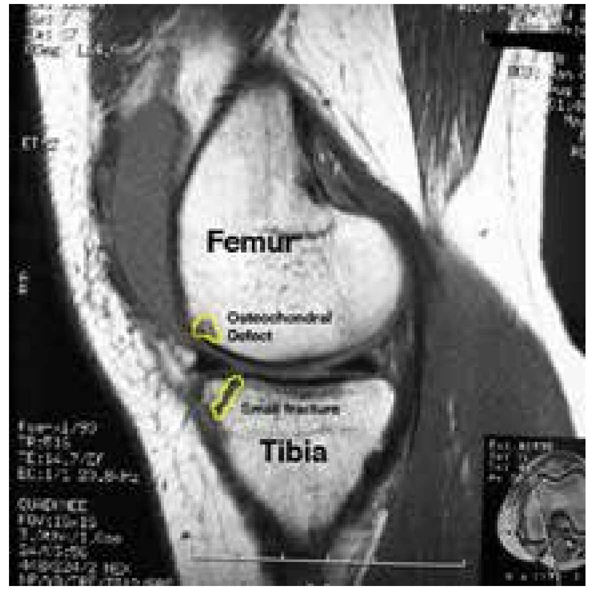
In athletes and military recruits, women have a higher incidence of stress fractures than men. The incidence of stress fractures, derived from 10 studies on athletes, is 9.7% in women and 6.5% in men. In military recruits, data from 11 studies indicates incidence rates of 9.2% in women and 3% in men.

Women with one or more of the three major conditions of the "female athlete triad" are especially at risk. This problem is discussed in detail under The Female Athlete Triad section later in this eBook. Studies have shown that female athletes who have either a history of stress fractures, low bone mineral content, low calcium intake, irregular menstrual periods, or who are pregnant have an increased risk. Pregnancy specifically increases the risk for a stress fracture to the femoral neck.

Some investigators have proposed that individuals with flat feet or high, rigid arches may be at increased risk.

Patients who have any medical problem or who are on medication that decreases bone mineral density (BMD) are at risk, as are those with a history of previous stress fractures. Athletically active children who are still growing and have not reached skeletal maturity are susceptible to this injury. Patients deficient in vitamin D and calcium frequently have decreased bone density and mass, which are well-acknowledged risk factors of stress fractures.

MRI of a 23-year old female soccer player who sustained a hyperextension knee injury and had pain when attempting to extend her knee. She has a small fracture in front of the tibia (outlined in yellow) and an osteochondral defect in the femur (outlined in yellow). This patient had a history of stress fractures and was found to be deficient in vitamin D. She had to sit out of the entire season to allow healing of both bone problems.



Medical Evaluation and Diagnosis

Clinical Presentation
Patients who have a stress fracture or an early “stress response” typically develop symptoms gradually. Pain at a specific site increases with activity and then diminishes with rest.

Patients usually wait and finally seek medical treatment when the pain has become severe and is interfering with their activities. There may be swelling in the area injured, which is very painful when touched. Bruising is also possible. If the injured area is on the lower extremity, hopping or jumping may be extremity painful or even not possible.

If the physician suspects a stress fracture or early stress response, they will determine if any risk factors exist and most likely order imaging tests. In athletes, questions will be asked to determine any recent changes in training schedules, surfaces, equipment, shoe wear, and so on. In sedentary patients, an assessment will be made to determine if a new exercise program was initiated or if an unusual physical activity was done such as an excessive amount of hiking on uneven terrain.

In patients who had no obvious change in activity or training, it is important to rule out a bone disease or other cause of the stress fracture. A consultation with a metabolic bone disease specialist may be warranted. In these cases, laboratory tests should be done to measure serum levels of calcium, phosphorus, creatinine, and vitamin D. Nutritional markers may be obtained in patients with a low body mass index (BMI), hormone levels should be measured in patients with amenorrhea (irregular monthly periods) or dysmenorrhea (pain with menstruation), and blood cell counts evaluated when required. In addition, a dual x-ray absorptiometry (DEXA) scan may be necessary in patients with a history of multiple stress fractures, post-menopausal women, or women with one or more of the three conditions related to the female athletic triad.

A rapid and accurate diagnosis is required to prevent a stress fracture from increasing in size and to reduce the amount of time required for rest and medical treatment.

Imaging
In most cases, the physician will obtain x-rays first. These are usually negative until the fracture begins to heal,

at which time they show new bone formation or callus on the film.

MRI is the most sensitive test for detecting early bone marrow edema. Studies have shown that MRI is 88-90% accurate in diagnosing stress fractures. This test can detect an early stress response and allow initiation of immediate treatment to prevent the stress fracture from occurring. Several years ago, a classification system was used to grade abnormal bone activity:

Grade 0: normal.
Grade 1: mild-to-moderate edema of the periosteum on T2-weighted images, no focal bone marrow abnormality.
Grade 2: more severe edema of the periosteum, and some edema of the bone marrow on T2-weighted images.
Grade 3: moderate-to-severe edema of both the periosteum and bone marrow on T1- and T2-weighted images.
Grade 4: low-signal fracture line on all sequences, severe marrow edema on T1- and T2-weighted images, may also show severe periosteal and moderate muscle edema.

More recently authors have described that a stress response (as seen on MRI) appears as a poorly defined, abnormal signal intensity of the bone marrow similar to that of a bone bruise. A stress fracture is seen as an irregular, incomplete, hypointense line which runs along the cortex (outer layer) of the bone.

A computed tomography (CT) scan is not as sensitive as MRI, but is indicated in patients with contraindications to MRI or those with claustrophobia. CT is the preferred imaging method to detect bone thinning, called osteopenia.

A 3-phase bone scan is important to diagnose a bone disease such as osteoporosis, rule out the presence of a tumor, and detect infection in the bone.
Ultrasound is useful for early diagnosis of stress fractures in the foot.

Patient Examples

Here are a few real-life patient cases that we have diagnosed and treated with stress fractures or stress reactions. All of these patients had normal x-rays and MRI was required to diagnose the injuries.

A 35-year old man who worked as a heating/cooling repair professional spent one day (8 hours) working in an attic. He banged his knee several times on wood trusses as he crawled around the small, cramped space. He noticed at the end of the day a new aching pain in his knee. Over the next 4 weeks, the pain became worse until it affected his daily activities. MRI showed a stress fracture, with extensive bone marrow edema on his lateral femoral condyle.

MRI showing a stress fracture of the lateral femoral condyle (LFC). The area outlined in yellow shows bone marrow edema, indicative of a stress fracture. P = patella.

This case shows that a stress fracture can occur from just one day of new, repetitive microtrauma to the knee. The patient was placed on rest, with no physical activity allowed for several weeks.

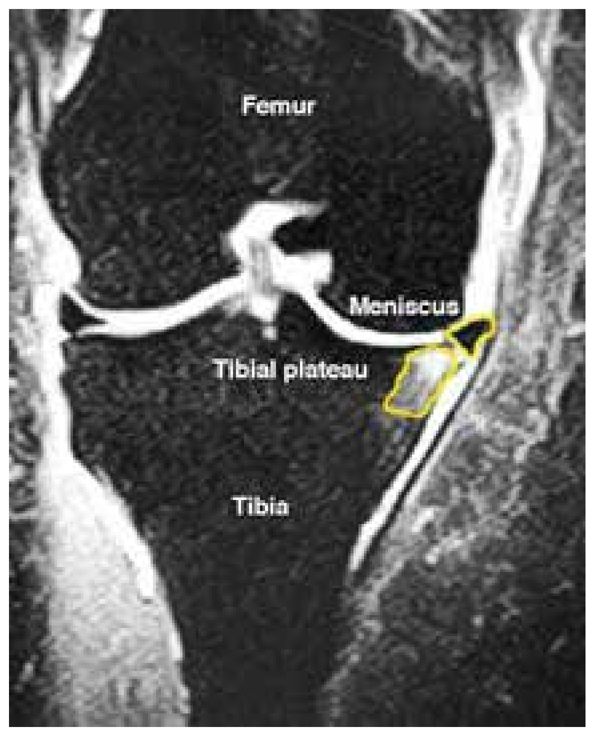
A 28-year old woman who was a recreational jogger decided to participate in a mini-marathon. She increased her training mileage and after 3-4 weeks, noted pain at the top of her tibia (shinbone). MRI showed a stress fracture on this area, called the tibial plateau.

She was advised to stop all activity for 16 weeks to allow the injury to heal. She was unable to participate in the mini-marathon.

MRI showing a stress fracture of the tibial plateau. The area outlined in yellow shows bone marrow edema, indicative of a stress fracture.

A 58-year old woman came to our clinic with symptoms of arthritis and pain in the inner (medial) portion of her knee. MRI showed that her medial meniscus was torn and “pushed” outside of the joint from where it is normally located. This is known as a degenerative tear because it happened gradually, without a specific injury. There was a loss of the normal amount of joint space in this area of her knee. Because the meniscus was no longer functioning and providing a cushion between the femur and tibia, the loads and forces incurred from simple daily activities had produced a stress fracture to the tibial plateau.

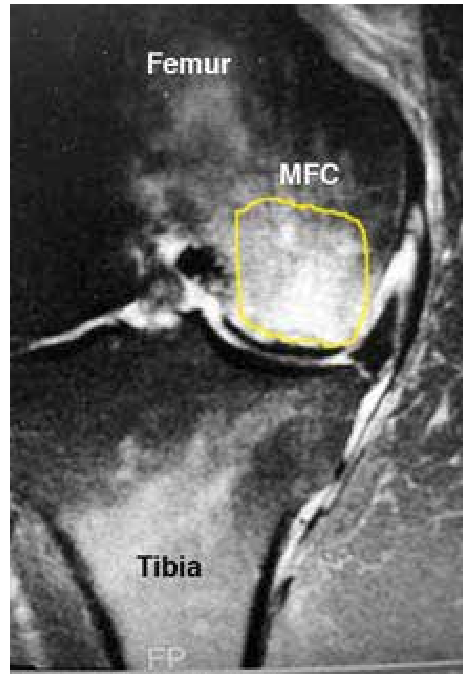
The patient underwent surgery in which a portion of her torn medial meniscus was removed. Unfortunately, her prognosis is poor, and we expect her arthritis to gradually worsen and to eventually perform either a partial or total knee replacement.



MRI showing a stress fracture of the tibial plateau. The displaced meniscus is the black structure outlined in yellow and the stress fracture is just below it, also outlined in yellow.

A 56-year old obese woman (BMI, 35) came to our clinic on crutches, complaining of severe pain in the inner (medial) area of her knee. She had jammed her knee while climbing down off of a stool and had immediate pain. MRI showed a stress reaction due to a problem with the blood supply in the femur - called avascular necrosis.

In this case, the stress reaction was due to a lack of normal blood supply and not to repetitive loading. The patient was advised to loose weight and bring her BMI below 30 before any operative procedures could be considered. The prognosis is poor when a stress reaction is accompanied with a decreased bone supply and death (necrosis) of the bone cells required for healing. The condition may progress to involve greater areas of the bone and increased knee pain.



MRI showing a stress reaction of the medial femoral condyle (MFC). The area outlined in yellow shows bone marrow edema and the stress reaction site.

Treatment

The treatment and amount of recovery time for a stress fracture depends on many factors. The physician will classify the injury as either low risk or high risk in regard to the potential of a delayed union, non-union, or development of a complete fracture. The factors taken into consideration are the location, direction of impact loading during weight bearing activities, the body's natural course of healing, and the blood supply to the bone.

Low risk sites

Hip: Femoral neck - inferior aspect, < 50% of femoral neck (compression fracture), pubic ramus
Leg: Tibial shaft (posteromedial cortex), fibula
Foot/ankle: 2nd-5th metatarsals, calcaneus, cuboid, cuneiform

High risk sites

Hip: Femoral neck - inferior aspect, > 50% of femoral neck (compression fracture); superior aspect (tension fracture)
Leg: Tibial shaft, anterior cortex
Foot/ankle: 5th metatarsal (just distal to diaphyseal-metaphyseal junction), 2nd metatarsal (proximal), navicular, talus, medial malleolus
Other: Seasamoid bones (bone embedded within a tendon, such as the patella in the knee)

The total amount of time for a stress fracture to heal depends not only on the factors we just described, but also on the presence of other problems such as low bone mineral density, poor blood supply, irregular menstrual periods, vitamin D deficiency, calcium deficiency, and the patient's compliance with rest and other medical treatments recommended by the physician.

Low risk stress fractures typically require 4-8 weeks of rest. A walking boot, brace, air cast, or splint may be used to help stabilize the area that is healing. Acetaminophen (Tylenol) and ice are used to control pain and swelling. No impact activities are allowed. Exercises of the non-involved upper and lower extremities are permitted, especially those done in a swimming pool. Crutches are used temporarily only if there is pain with weight bearing. It is still important to be active and maintain physical functional levels.

High risk stress fractures may require many more weeks - up to 12-16 - if treated conservatively. These types of stress fractures are often treated with immobilization in a cast or brace and crutches are used to prevent weight-bearing forces. Surgery may be required if there is a potential for a nonunion or complication at the fracture site. Internal fixation is done with medical grade pins, plates, and screws to secure the fracture site to allow healing.

Some authors have suggested surgery as a valid treatment option for navicular stress fractures due to the poor blood supply of this bone, and for medial malleolus stress fractures because they have a high incidence of displacement and nonunion. Stress fractures to the tibia (anterior cortex) may be treated initially with a long period of immobilization and protected weight bearing, but may require surgery if no healing occurs within 4-6 months. Compression stress fractures involving more than 50% of the inferior surface of the femoral neck and tension fractures located on this bone's superior aspect require internal fixation.

In all patients, a slow resumption of activities is paramount to avoid a reoccurrence of the stress fracture. We recommend working with a physical therapist who can safely and effectively guide the activity program and progression back to pre-injury levels. Athletic training may begin when no pain is felt with daily activities and imaging studies show no abnormalities. The patient should begin with non-weight bearing, non-impact activities such as swimming and cycling. Then, progression to weight-bearing, non-impact activities is allowed such as a stair machine or a treadmill. Many strengthening and flexibility exercises are described in detail under the Home Exercises for Strengthening and Flexibility section of this eBook. When these activities can be done for long periods of time without pain, the patient may gradually begin impact activities such as jogging. We recommend to slowly increase mileage and eventually return to full activities. A good rule to follow is to not increase the volume of athletic training by more than 10% each week.

Questionable Treatment Therapies

Pulsed ultrasound has been suggested by some studies to treat stress fractures to reduce healing time. However, other studies have refuted this finding. Extracorporeal shock wave therapy has also been suggested, but clinical trials have yet to show its effectiveness.

Potential Problems, Reoccurrence Issues, and Long-term Damage

Stress fractures that do not fully heal lead to chronic pain. If the underlying cause is not addressed, there is an increased risk for reoccurrence. If left untreated, stress fractures may enlarge to become complete fractures. These fractures can take an abnormally long time to heal or not completely heal. Surgery may then be required. Untreated pars stress fractures of the spine may lead to spondylolysis, a permanent pars defect on both sides of the spine.

Vital Minerals for Bone Health: Vitamin D and Calcium

The most significant nutritional influence on bone health is calcium; 99% of the calcium in the body is contained in bone. The mechanical strength of bone is directly related to its mineral content, and the two principal minerals are calcium and phosphorus. An appropriate amount of mineral intake helps maintain bone mass, whereas a limited amount may adversely affect bone integrity and remodeling capabilities. Calcium is found in green vegetables and milk and milk products. Phosphorus is available in milk, meat, and other protein-rich foods.

The main function of vitamin D is to maintain calcium and phosphate homeostasis (normal, natural state) within the body by targeting certain areas, including bone and skeletal muscle. The major source of vitamin D is provided through the interaction of the skin with ultraviolet sunlight. The dietary intake of foods such as fatty fish, eggs, and dairy products provides only a minor amount of total vitamin D intake. In addition, vitamin D production is influenced by an individual's age, geographic location, and skin pigmentation.

In athletes, training indoors, participating in winter sports, and living in northern latitudes may lead to vitamin D deficiency. Studies conducted in the northern hemisphere show athletic performance consistently improves in the summer, peaks in late summer months when sun exposure is maximal, and then gradually declines in winter months despite year-long training programs. Several investigations found a relationship between athletic performance and vitamin D levels. One study from the University of North Caroline, Chapel Hill, proposed that peak athletic performance may occur when vitamin D 25(OH)D levels are at least 50 ng/mL, although further randomized, controlled clinical trials are required to verify this hypothesis.

Adults with low vitamin D levels may have decreased muscle mass, with atrophic changes mostly found in type II muscle fibers. These problems may be reversed with calcium and vitamin D supplementation. Low vitamin D levels have a negative effect on BMD in adults. Supplementation of calcium and vitamin D has been shown to successfully decrease the incidence of stress fractures in female military recruits.

One study of 125 young female cross-country runners (average age, 22 years) found that athletes who had higher intakes of calcium and dairy products had a lower rate of stress fractures. In fact, each additional cup of skim milk consumed each day was associated with a 62% decrease in stress fracture incidence. High intakes of skim milk, dairy foods, calcium, animal protein, and potassium were associated with significant gains in whole-body BMD and bone mineral content.

The best measure of vitamin D is the serum concentration of the inactive 25(OH)D3 level which represents the level from dietary intake, sunlight exposure, and adipose stores. A normal range is 30-50 ng/mL (nanograms per milliliter). Option calcium absorption requires at least 30 ng/mL in healthy adults. The normal range may be achieved with supplementation of 600 International Units (IU) per day, which is the current recommended daily allowance in the United States. Several studies have found that athletes typically have vitamin D deficiency, should be corrected for both potential performance enhancement as well as reduction in the risk of injuries including stress fractures.

In 2011, the Food and Nutrition Board of the U.S. National Academy of Sciences recommended these following minimum daily allowances for adults:

Vitamin D: 600 IU
Calcium: 1,000 mg
Phosphorus: 700 mg

For patients with vitamin D deficiency, the following treatment regimen was recently recommended by physicians from the Hospital for Special Surgery in New York:

50,000 IU capsules of vitamin D2 every week for 8 weeks
50,000 IU capsules of vitamin D2 every 2 to 4 weeks for maintenance, based on serum concentration levels measured at 8 weeks.

The Female Athlete Triad

For some young female athletes, the combined pressures of the desire for athletic success and the maintenance of a very thin body appearance can lead to what is termed the female athlete triad. This condition consists of 3 major problems:

1. An abnormally low BMI from low energy availability (also called an energy deficit), due to either disordered eating, an eating disorder, or failure to consume enough calories to maintain a positive energy balance.
2. Lower than normal BMD or bone mass.
3. Abnormal or absent menstrual periods, classified as either oligomenorrhoea (infrequent menstrual periods) or amenorrhoea (absence of menstrual periods).

Energy availability is defined as the amount of energy consumed minus the amount of energy used during exercise divided by fat-free mass. Low energy availability is a condition in which the body is so depleted from lack of calories, it has to reduce the amount of energy that is used for basic physiological functions. This problem affects reproductive function, growth, maturation, and bone formation. In women, it triggers changes in the endocrine system (hypothalamo-pituitary-gonadal axis) that affects normal menstruation. These women have an estrogen deficiency which may prevent the attainment of peak bone mass and increase the rate of bone turnover. These problems are associated with an increased risk of stress fractures (2- to 4-fold increase compared to female athletes who do not have the disorder) and the development of osteoporosis later in life.

The American College of Sports Medicine (ACSM) published clinical guidelines in 2007 and the Medical Commission of the International Olympic Committee (IOC) did the same in 2009 in regard to the diagnosis and treatment of this condition. The ACSM recommends a DEXA scan for pre-menopausal women that have:

- Oligomenorrhoea or amenorrhoea of > 6 months duration
- Disordered eating or an eating disorder of > 6 months duration
- Presence of stress fracture or other fracture from minimal trauma

The sites to scan are the lumbar spine, hip, and the distal forearm. The results provided include BMD, a T score (how the athlete's BMD compares with women in their thirties), and a Z score (comparison of the athlete's BMD with others of similar age).

The ACSM defines a low BMD as a Z-score that falls between -1.0 and -2.0. This society also includes a history of nutritional deficiency, hypoestrogenism, stress fractures, and/or other secondary clinical risks for fracture in their definition of low BMD. The ACSM lists osteoporosis as a secondary clinical risk factor for fractures of Z-score less than -2.0.

Athletes who appear to be at high risk for suffering one or more of the female athlete triad diagnoses include long-distance runners, gymnasts, and figure skaters. Unfortunately, many women suffering from the female athlete triad do not seek medical attention until they sustain a stress fracture. On average, they have 10% lower BMD compared to athletes who do not have the disorder. In addition, they may lose 2-3% of their bone mass each year if left untreated. The bone that has been compromised during the adolescent years - when half of peak bone mass acquisition normally occurs - may not recover to normal levels in adulthood.

DEXA scans are limited because they cannot estimate bone strength. This requires a 3-dimensional imaging technique such as axial quantitative CT which can measure bone geometry, bone mass, and volumetric bone mineral density.

The most common pharmacological treatment for the female athlete triad is estrogen therapy. Unfortunately, this therapy has not been shown to improve BMD or bone mass. While bisphosphonates are commonly used in postmenopausal women with osteoporosis, the Medial Commission of the IOC does not approve their use in premenopausal women. In addition, a review of the medical literature by researchers in Canada found that bisphosphonates failed to improve BMD in anorexic women. Other therapies such as androgens, calcium, and vitamin D supplementation have been recommended, but little evidence exists that they improve bone health in female athletes with the triad disorder.

Strategies to gain body weight and increase BMI appear to have the best chance of improving bone health. These include a simultaneous reduction in training and increase in caloric intake. Athletes may benefit from working with a nutritionist in order to become educated on ways to increase their caloric intake in a healthy and beneficial manner. In addition, women with the complete female athlete triad disorder require consultation with a psychologist or psychiatrist to address the underlying reasons for their behavior and eating problems.

Changing training from intensive cardiovascular work-outs to resistance weight-training has been recommended by the American Physical Therapy Association in order to reduce low energy availability and increase BMD. Resistance training to improve bone health usually involves the athlete performing 3 sets of 8-12 repetitions of 6-10 different exercises at approximately 80% of their 1-repetition maximum. This should be done 3 times a week on alternating days. In addition, cross-training whereby a high-impact exercise such as running is replaced with a low-impact exercise such as cycling is also of benefit.

For further information, see the Female Athlete Triad Coalition's website at http://www.femaleathletetraid.org.

Prevention

The best way to prevent a stress fracture is to avoid an excessive and rapid increase in training. Start any new sport or training program slowly; use periodization principles. Gradually increase training over 3 weeks, follow by a period of relative rest for 1 week. Avoid a sudden change in training surface. For instance, do not change from running only on flat, even ground to running only on large hills with uneven terrain. If a change in training surface is required, do so gradually.

Alternate high-impact and low-impact activities such as swimming/cycling. Wear proper sports equipment, especially shoes. Make sure not to train in shoes that are worn or not properly designed for the specific activity, such as long-distance running. Do strength training to prevent early muscle fatigue and prevent loss of bone density that occurs with aging.

Maintain a healthfully diet that includes foods rich in calcium and Vitamin D (fatty fish, eggs, dairy products). Studies have shown that female athletes and military recruits who consume more than 1500 mg of calcium daily have a large reduction in stress fractures. Make sure you consume enough calories to maintain normal energy availability. Women who miss more than 3 monthly menstrual periods should be evaluated, even if they do not have the other two problems associated with the Female Athlete Triad.

Insufficiency Fractures (Occult Fractures)

As we previously mentioned, there is another type of minor fracture or microcracking that may happen that is different from a stress fracture because it occurs from normal or a small amount of force in bone that is abnormally weak. An insufficiency fracture, also called an occult fracture, usually occurs in patients with a metabolic bone disease such as osteoporosis or Paget's disease.

Common sites for insufficiency fractures are the vertebrae, pelvis (sacrum, pubic rami), neck of the femur, the sternum, the feet, and the forearm. Well-known factors that increase the risk of sustaining these types of fractures are osteoporosis, age (elderly), post-menopause in women, prior radiation therapy and chemotherapy, chronic renal failure, rheumatoid arthritis, prior hip surgery, use of corticosteroids, long-term use of bisphosphonate therapy in postmenopausal women, and pediatric patients with anorexia, rickets, scurvy, or osteogenesis imperfecta.

As we described for stress fractures, x-rays are usually negative in insufficiency fracture sites until bone healing occurs with formation of callus. MRI is the preferred method to detect insufficiency fractures and their exact location. CT scans are valuable in cases of ankle or foot pain, especially when an initial diagnosis of an ankle sprain is made but the pain does not resolve. CT scans can detect subtle fracture lines and bone loss.

Low back, hip, and arm pain may be misdiagnosed as tumors, infection, or osteonecrosis and result in unnecessary, costly procedures. This is especially true in the elderly, where insufficiency fractures are commonly due to osteoporosis in these regions. If left untreated, insufficiency fractures in areas such as the knee and hip may progress to necrosis and accelerate arthritic degeneration.

Avascular Necrosis (Osteonecrosis)

We have mentioned that the blood supply bones receive is an important factor in the healing of stress fractures. There is a condition known as avascular necrosis (also called osteonecrosis) in which the blood flow to the bone is completely interrupted and the bone tissue essentially dies. The femoral neck/head in the hip joint is the most commonly affected area in the body, followed by the knee joint, where osteonecrosis occurs in the femoral condyles. The condition may also occur in the jaw, ankle (talar neck), and wrist (scaphoid).

Risk factors for avascular necrosis are:

- Gender and age (men aged 30-60 have an increased risk)
- Severe fractures
- Joint dislocations
- Long-term use of high-dose corticosteroids
- Use of bisphosphonates for osteoporosis
- HIV/AIDS
- Lupus
- Diabetes
- Sickle cell anemia

- Osteoporosis
- Alcoholism
- Radiation therapy for cancer
- Dialysis for kidney failure
- Organ transplantation

There is also a more rare condition known as spontaneous osteonecrosis of the knee (SONK) that may cause an insufficiency fracture. SONK usually occurs on the medial femoral condyle and is frequently associated with a medial meniscus tear. Women are more likely to sustain this type of fracture, as are patients over the age of 55. Patients seek medical treatment for the sudden onset of severe pain directly on the medial portion of the knee. Most patients do not sustain an injury, and many complain of pain with all daily activities and at night.

There currently exists debate among orthopaedic surgeons on whether SONK occurs as a result of spontaneous necrosis or happens as a result of an insufficiency fracture. This is especially true in elderly women with osteopenic bone that is already susceptible to insufficiency fractures. In either case, the condition gradually leads to osteochondral damage and osteoarthritis.

Avascular necrosis - whether of spontaneous or long-term origin - may cause the bone to collapse, resulting in severe pain and loss of joint function. It is a degenerative process, and usually results in the necessity for a total hip or knee replacement.

Bone Bruises

What is a Bone Bruise?

A “bone bruise” is a traumatic injury which impacts a portion of the bone - either the periosteum, the marrow, and/or the subchondral bone. This injury may also be referred to as a bone contusion, bone marrow lesion, or bone marrow edema. Bone bruises are believed to represent microfractures of trabeculae (located in the medullary cavity) and bleeding in the marrow. The overlying cortical bone is not disrupted.

How Bone Bruises Happen

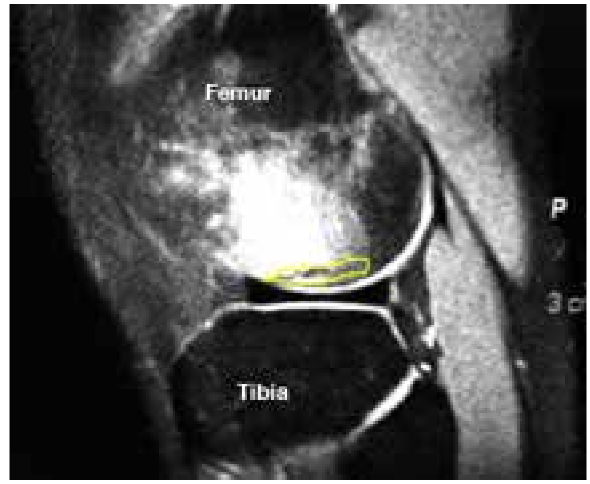
Bone bruises usually come from a direct and sudden compressive force through contact with an object, such as a knee striking the dashboard in a car accident. This injury may also happen from a force that is not quite strong enough to break a bone, or during a severe twisting injury that causes a ligament to tear in the knee or ankle. Bone bruises may happen due to excessive, repeated forces to the bone, such as in military training. Bone bruises have also been identified in patients with chronic osteoarthritis of the knee. There are 3 types of bone bruises:

Subperiosteal hematoma
Bleeding occurs underneath the periosteum of the bone. This injury usually happens from a direct high-force trauma on the bone.

Interosseous bruise
Bleeding occurs inside the bone where the marrow is located. The blood supply within the bone is damaged, which causes bleeding. This injury frequently happens due to a repetitive, high compressive force on the bone.

Subchondral bruise
The subchondral bone separates from the articular cartilage, with bleeding occurring in-between. This injury usually occurs from an extreme compressive force, or a shearing force such as a violent twist.

A severe bone bruise may also be accompanied by damage to the articular cartilage and a fracture of the osteochondral surface, especially in cases of anterior cruciate ligament (ACL) tears and patellar dislocations. A portion of the subchondral bone may shear off, along with the cartilage. Some investigators have speculated that this more complex injury may cause premature osteoarthritis in the knee joint.

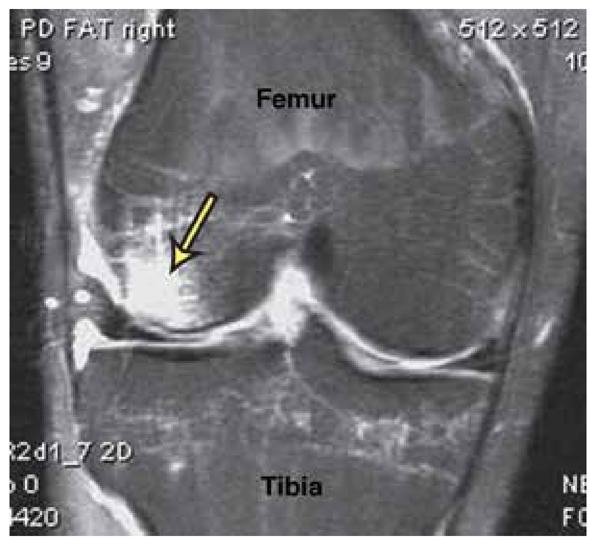


MRI of a 20-year old collegiate soccer player who jammed his knee and had pain with running for the next 3 days. His x-rays were negative, but the MRI shows a small osteochondral fracture on the femoral condyle (outlined in yellow) and bone edema. He missed the entire season because the damage required 8 weeks to heal.

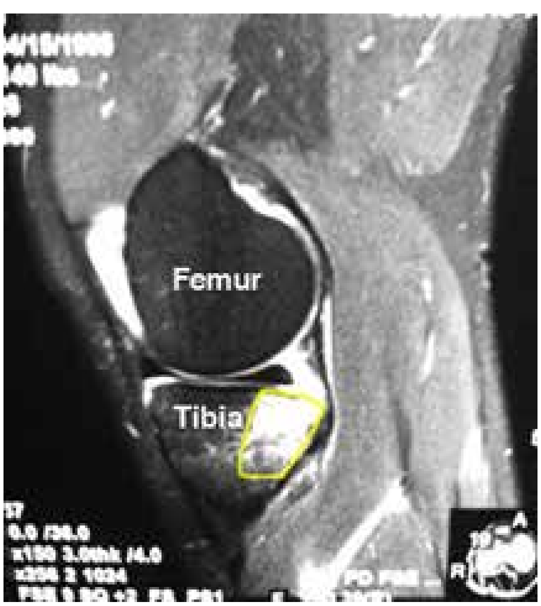
Where Bone Bruises Occur

Bone bruises may occur throughout the body:

- Femur (end of the femur - femoral condyle - most frequent)
- Tibia (top of the tibia - tibial plateau - most frequent)
- Kneecap (patella)
- Hip and pelvis (trochanter, cervical areas)
- Ankle (talus, caudal tibia epiphysis most common areas)
- Wrist (scaphoid)
- Heel and foot



MRI showing a bone bruise (yellow arrow) on the end of the femur (femoral condyle).



MRI showing a large bone bruise (outlined in yellow) on the tibia that occurred during an injury to the ACL.

Risk Factors

- ACL tear (bone bruise present in nearly all)
- Tears to the other ligaments in the knee (posterior cruciate ligament, lateral collateral ligament, medial collateral ligament)
- Fall on the knee, trauma to the knee
- Severe ankle sprain, especially syndesmosis or high ankle sprain
- Hip fracture
- Dislocated kneecap (bone bruise present in nearly all)
- Medial meniscus tear

Medical Evaluation and Diagnosis

Patients with a bone bruise (and frequently other injuries) present with severe pain and frequently swelling. There may be discoloration to the injured site. The physician will most likely obtain x-rays initially; however, a bone bruise can only be detected with MRI.

Treatment

The treatment of a bone bruise is based on the extent of the injury and if other structures, such as the ACL, are damaged. The patient is advised to rest for as long as necessary until pain and swelling are no longer present. Ice packs should be used for pain and swelling for 15-20 minutes at a time, 4-8 times a day as needed. If the bone bruise is in the leg, it should be elevated to reduce swelling if this is a problem. An elastic bandage or compression sleeve may also be used to control swelling and for support.

Nonsteroidal anti-inflammatory medications such as ibuprofen (Advil, Motrin), naproxen (Aleve), or acetaminophen (Tylenol) may help, but should only be used if directed by a physician. It is important to avoid placing large loads on the injured area.

Bone bruises take a varying amount of time to heal, depending on the location and severity of damage. One study from the Netherlands reported an average of 42 weeks elapsed between a traumatic knee injury (tear to a ligament or meniscus) and healing of the initial bone bruise. That study found that the presence of osteoarthritis, age, type of bone bruise, and the number of bone bruises were related to healing time. There is very little that can be done for a bone bruise other than to treat the pain and swelling and rest. There are no specific medications or treatments to accelerate healing other than avoiding activities that cause pain and make the condition worse. Patients should understand that some of these injuries take many months to heal.

Potential Problems, Reoccurrence, and Long-Term Damage

With ACL tears, severe bone bruises may lead to early osteoarthritis. One recent study from New York found that all patients sustained a bone bruise (of different types of severity) and that the progression of cartilage damage in the more serious cases was substantial just 5 to 7 years after the injury. Other investigations have reported incidence rates of bone bruises with ACL tears from 84% to 95%. While some of these bone injuries appear to resolve, others persist and correlate with poorer functional outcomes.

Patients who suffer a traumatic patellar dislocation injury commonly have bone bruising of the patella and lateral femoral condyle. One study from Finland found that bruises were still present on MRI in 39% of patients 1 year after this injury. The authors concluded that a large bruise may be associated with subsequent arthritic damage of the patella.

The natural history of isolated bone bruises is unclear. This is mostly due to the lack of long-term, prospective clinical studies.

Shin Splints

What are Shin Splints?

"Shin splints" is a commonly used term that indicates pain in front, along the inner edge, or just behind the shin bone (tibia). The term shin splints simply indicates pain in this area - it is not a diagnosis. It is important to realize that tibial pain may be due to different reasons, the most common of which are:

- Medial tibial stress syndrome, which has been defined as periostitis (swelling of the periosteum - the tissue that covers the bone), tendinitis, or small tears of the calf muscles where they attach to the tibia
- A stress fracture or stress reaction
- Chronic, exercise-induced anterior compartment syndrome
- Peripheral nerve entrapment
- Popliteal artery entrapment syndrome
- Bone infection, osteomyelitis
- Tibial tumor

It is therefore important for a physician to determine what is causing pain in or around the tibia and determine if it is arising from a soft tissue (muscle or tendon) problem, a bone abnormality, or another source. We have found that pain in the very front of the tibia is usually due to a stress reaction or stress fracture, while pain in other areas is due to inflammation or small tears to muscles or their attachments to the tibia - what we and others term medial tibial stress syndrome (MTSS). Because we have already discussed bone problems such as stress fractures and stress reaction previously in this eBook, we will focus on MTSS in this section.

How Medial Tibial Stress Syndrome Happens

MTSS is usually caused by excessive force on the lower leg. The tibia has many muscles attached to it that control the movement of the foot and ankle.

Superficial muscles of the right lower leg (anterior view)
Superficial muscles of the right lower leg (posterior view)
Deep muscles of the right lower leg (posterior view)

Patients with MTSS have pain along the medial (inside) edge of the tibia. The stress or force that causes pain usually comes from too much athletic training over a short period of time, poor shoes, poor technique, or an improper training surface. Long distance running or performing other athletic activities such as jumping excessively or improperly can cause this problem. MTSS may also occur after running downhill or on a slanted or tilted surface. Running in shoes that are worn or that are not appropriate for running can also cause this problem.

Muscle weakness, imbalances, or tightness may contribute to the problem. The muscles that are usually associated with MTSS are the gastrocnemius, soleus, tibialis anterior, flexor digitorum longus, and plantaris.

There is disagreement in the medical literature on what exactly causes MTSS. Some studies have shown that excessive forces from the muscles of the lower leg cause them to "pull" on their origin or insertion sites along the tibia. One theory is that the excessive stress these muscles generate on the tibia results in inflammation where they attach to the periosteum of the tibia. The shin pain is believed to be due to irritation or inflammation of the periosteum from this constant pulling. However, other studies refuted these findings and believe that the bone of the tibia is involved to varying degrees. Some researchers believe the forces on the tibia and fatigue of the calf muscles cause the tibia to bend or bow slightly, which can contribute to MTSS.

Risk Factors

There are several risk factors for the development of MTSS, including:

- Long-distance running
- Ballet dancing
- Military training, especially in women
- Participating in sports with sudden stops and starts such as basketball, tennis, soccer
- Hiking on uneven terrain or walking up and down large hills
- Use of improper footwear
- Foot problems: flat feet, excessive pronation, navicular drop
- Sudden increase in intensity of training that includes high-impact activities
- Excessive training on hard surfaces such as concrete
- Excessively tight calf and ankle muscles
- Poor strength in hip, thigh, calf, and ankle muscles
- Poor form during training or athletic activity
- High BMI

Medical Evaluation and Diagnosis

Patients who seek medical treatment for shin pain have tenderness or pain along the front, inner, or just behind the shin bone. The pain may be aching, burning, or throbbing. There also may be mild swelling. In the early stages, activity increases pain and rest alleviates it. As the problem progresses, pain may occur during low intensity activities and may even continue with rest. If not treated effectively, the pain becomes severe, with increased swelling and warmth present along the shin.

X-rays are usually performed first, but they typically do not show any abnormalities. If symptoms persist and are not alleviated by a few weeks of rest, a MRI may be obtained which will detect periosteal edema if MTSS is the source of the problem. MRI is also useful to rule out other diagnoses such as a stress fracture, stress reaction, chronic compartment syndrome, tendinitis, or nerve entrapment.

Treatment

A short period of rest is almost always successful in alleviating pain from MTSS. Participation in athletics and high impact activities should be stopped for as long as necessary until pain and swelling are no longer present. Patients may perform low-impact or no-impact activities such as swimming and cycling if these do not cause pain.

Ice packs should be used on the shin for pain and swelling for 15-20 minutes at a time, 4-8 times a day as needed. The leg should be elevated to reduce swelling if this is a problem. An elastic bandage or compression sleeve may also be used to control swelling and for support.

Nonsteroidal anti-inflammatory medications such as ibuprofen (Advil, Motrin), naproxen (Aleve), or acetaminophen (Tylenol) may help, but should only be used if directed by a physician.

If the patient has flat feet or hyperpronates, arch supports or orthotics should be obtained based on a recommendation by a physician or physical therapist. Proper shoes are essential for athletic activity, especially running.

Physical therapy is required and consists of strengthening and stretching exercises to be described in the next section. Modalities such as ultrasound, soft tissue massage, electrical stimulation may be helpful. Retraining of activities such as running and jumping/landing for proper form and technique should be done when required.

A slow resumption of athletic activities is required to avoid a reoccurrence of MTSS. Athletic training may begin when no pain is felt with daily activities. The patient should begin with low- or non-impact activities such as swimming and cycling. Then, progression to weight-bearing, non-impact activities is allowed such as a stair machine or a treadmill. Many strengthening and flexibility exercises are described in detail under the Home Exercises for Strengthening and Flexibility section of this eBook. When these activities can be done for long periods of time without pain, the patient may gradually begin impact activities such as running. We recommend to begin easy jogging on even surfaces and to slowly increase mileage. A good rule to follow is to not increase the volume of athletic training by more than 10% each week.

Potential Problems, Reoccurrence Issues

If MTSS becomes chronic and is ignored, the problem may progress to a stress reaction, stress fracture, or even a complete fracture. One clinical investigation demonstrated that some patients with chronic (long-standing) MTSS also had bone involvement consisting of decreased bone density and osteopenia (thinning) of the tibial cortex. If the factors causing the problem are not corrected, or if an athlete attempts to return to excessive training too soon, the problem may reoccur.

Prevention

The best way to prevent MTSS is to avoid an excessive and rapid increase in training. Start any new sport or training program slowly; use periodization principles. Gradually increase training over 3 weeks, follow by a period of relative rest for 1 week. Avoid a sudden change in training surface. For instance, do not change from running only on flat, even ground to running only on large hills with uneven terrain. If a change in training surface is required, do so gradually.

Alternate high-impact and low-impact activities such as swimming/cycling. Wear proper sports equipment, especially shoes. Do strength training and flexibility exercises to maintain adequate muscle endurance and flexibility.

Home Exercises for Strengthening and Flexibility of the Lower Extremity

Listed below are some simple exercises you may do at home to help strengthen and improve the flexibility of your foot, ankle, leg, and hip muscles. We strongly believe that you should be under the care of a physical therapist that can guide your exercise program. There are other exercises that may be done in the physical therapy clinic under direct supervision. In addition, your therapist will help progress your exercise program in a safe manner and make sure that the strength training does not cause further pain. Always do the stretches last in your exercise sessions. If any of these exercises cause pain, stop immediately. Your entire program should be tailored to the sport or activity you wish to return to upon your medical release.

Toe Raises

From a standing position, rise up onto the toes of your feet, taking your heels completely off of the ground. Hold for 1-2 seconds and then slowly return to the starting position. This exercise may be done initially sitting if required. Start with 1 set of 15 repetitions. Increase to 2-3 sets as tolerated. Then, progress to using just one foot (single-leg). This exercise may also be done on a step to allow the heel to hang as far down as possible and then raise up on the toes as far up as possible. Hold onto a stable object for balance and control if necessary.

Heel Raises

From a standing position, keep your heels on the ground and raise the toes of your feet as high as possible. Hold for 1-2 seconds and then slowly return to the starting position. Hold onto a stable object for balance and control if necessary. This exercise may be done initially sitting if required. Start with 1 set of 15 repetitions. Increase to 2-3 sets as tolerated.

Wall Shin Raises

Sit against a wall with your feet about 1 foot away from the wall and your knees slightly flexed. Keeping your heels on the ground, bring the toes of both feet up as high as possible towards your shins, then slowly lower your feet back towards the ground. Stop just before your forefeet touch the ground. Do 1 set of 12-15 repetitions. Then, from the same position, repeat the exercise except do as quickly as possible over a smaller range of motion. Do 1 set of 12-15 repetitions.

Increase the slow and fast exercises to 2-3 sets as tolerated. Then, progress to performing the exercise on a single leg. Rest the opposite foot on the wall behind you. Begin with 1 set of 12-15 repetitions per foot and progress to 3 sets on each.

Toe and Heel Walking

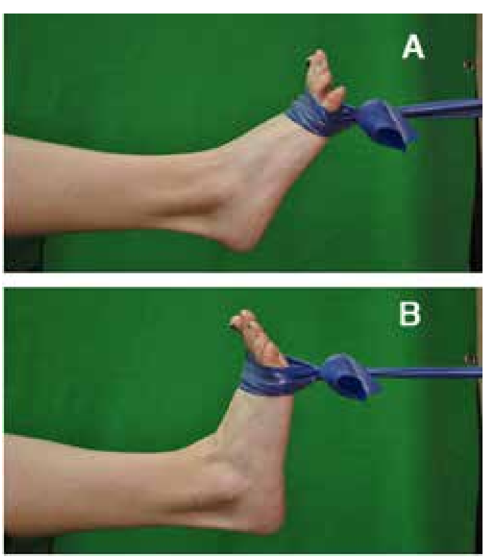
Walk up on your tiptoes as high as possible with your toes pointed straight ahead. Keep your knees relatively straight and your steps small. Go as far as possible until you feel a "burn" in your calf muscles. Then, walk on your heels with your toes pointed straight ahead. Use the same distance for both toe and heel walking.

Alphabet in the Air

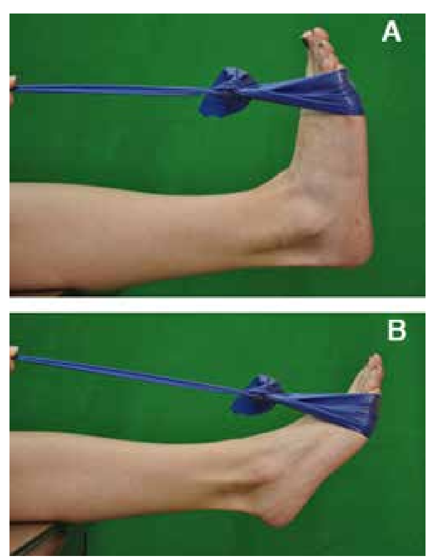
Using your big toe as a "pointer", trace the letters of the alphabet in the air, A through Z, then go from Z to A. Perform sitting or standing on 1 leg, 3 x/day.

Ankle Resistance Band Exercises

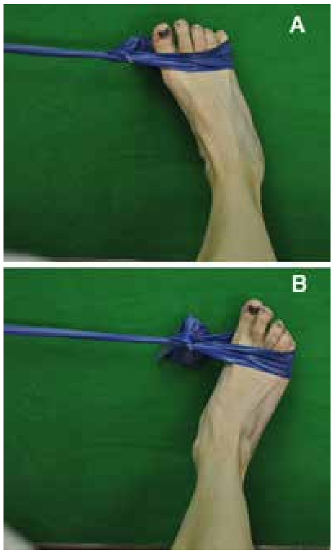
These exercises are performed in a sitting position with a resistance band or rubber tubing tied around your foot as shown below. Secure the other end of the band or tubing around a heavy object. You will change the position of your foot (from the starting to the ending position) as shown in the photographs below. Move the foot with the band in the desired direction as far as possible. Perform 1 set of 12-15 repetitions, rest for 1 minute, then perform another set. Increase the number of sets as tolerated. Perform these exercises on both legs.



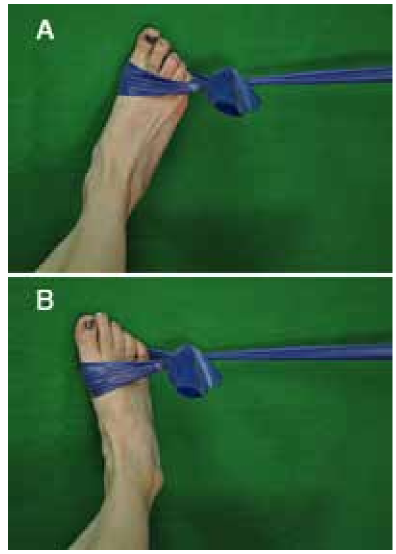
Ankle resistance band exercise for dorsiflexion in the (A) starting and (B) ending positions.



Ankle resistance band exercise for plantarflexion in the (A) starting and (B) ending positions.



Ankle resistance band exercise for eversion in the (A) starting and (B) ending positions.



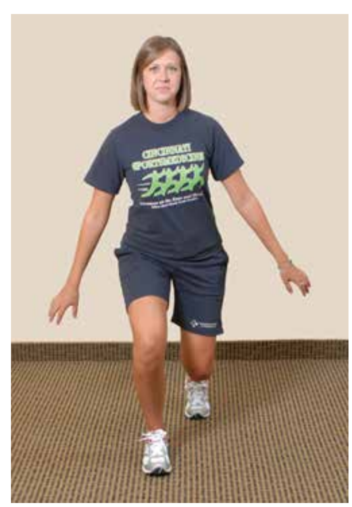
Ankle resistance band exercise for inversion in the (A) starting and (B) ending positions.

Wall Sits

Wear gym shoes for this exercise. Stand in front of a wall and place your feet about 2 feet away from the wall. Then, sit against the wall until your knees are flexed to 60-70 degrees. Feel the quadriceps muscles in both legs with your hands, which should feel equal. Wait until you feel a burn in your quadriceps and then hold this position as long as possible to achieve fatigue. Then, carefully stand up, rest for 2-5 minutes, then repeat the exercise. Perform 4 times a day. As you progress, you may place a ball between your knees and squeeze it as hard as possible for the entire exercise. You may also sit a little lower, to 90 degrees if possible, provided no pain is felt in your kneecap or patellar tendon.

Lunge, Straight

From a standing position, step straight ahead with one leg out as far as possible. Bend the knees and lower the back leg toward the ground. Only go down as far as you can without experiencing pain in your kneecap. Keep the front knee over the ankle and keep your back straight and head up, looking forward. Hold for 2 seconds, then return to the starting position. Repeat 10 times, rest for 1 minute, and perform 10 more times. Perform on both legs.



Lunge, Lateral

From a standing position, hop to the side with one leg as far as possible. Land on that leg, bend the knee as much as possible without experiencing any pain in your kneecap, and keep the other leg off of the ground. Balance and hold for 2 seconds, then return to the starting position by hopping back to the starting position using the opposite leg. Repeat 10 times, rest for 1 minute, and perform 10 more times. Perform on both legs.

Lunge, Diagonal

It is helpful for this exercise to create a “Y” shape on the floor with masking tape. From a standing position, hop out with one leg as far as possible diagonally (at an angle) to the left side. Land on that leg, bend the knee as much as possible without experiencing any pain in your kneecap, keeping the other leg off of the ground. Return to the starting position by hopping back with the opposite leg. Repeat 10 times, rest for 1 minute, and perform 10 more times. Perform on both legs.

Mini-squats

From a standing position, squat down to a 45-degree angle. Hold for a few seconds and then slowly rise back up. Perform 3 sets of 20 repetitions each. This exercise may also be done on an unstable surface, such as foam, cushion, or rocker board.

Hamstring Curls, Ankle Weight

This exercise may be performed either from a standing position or lying on your stomach. Attach a small ankle weight and bend your knee from 0-90 degrees behind you as shown below. Perform 3 sets of 10 repetitions. Rest for 1 minute between sets. Perform on both legs.

Straight Leg Raise: Hip Flexion

Lie on your back. Tighten your thigh muscle, keep your knee as straight as possible, and lift your leg straight up off of the bed or floor. Hold for 3 seconds, then lower the leg back to the starting position. Perform 1 set of 10 repetitions, rest for 30 seconds, and repeat the exercise 2 more times for a total of 30 repetitions. Add weight around your ankle as the exercise becomes easy to complete. Perform on both legs.

Straight Leg Raise: Hip Extension

Lie on your stomach. Keeping your knee straight, lift your leg toward the ceiling. Hold for 3 seconds, then lower the leg back to the starting position. Perform 1 set of 10 repetitions, rest for 30 seconds, and repeat the exercise 2 more times for a total of 30 repetitions. Add weight around your ankle as the exercise becomes easy to complete. Perform on both legs.

Straight Leg Raise: Hip Abduction

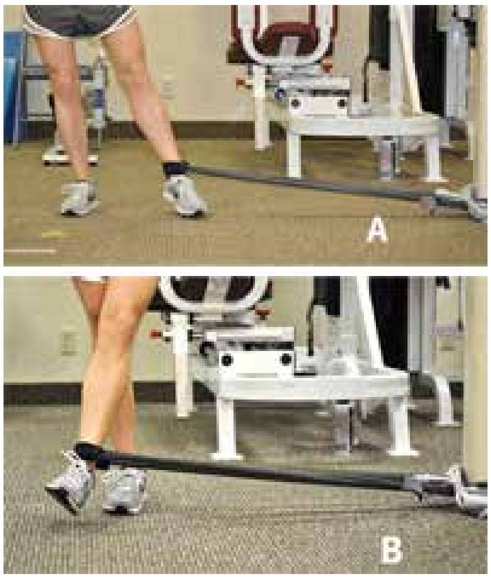
Lie on your side, the opposite of the leg that is painful. Keeping your knee straight, lift the leg up sideways toward the ceiling. Hold for 3 seconds, then lower the leg back to the starting position. Perform 1 set of 10 repetitions, rest for 30 seconds, and repeat the exercise 2 more times for a total of 30 repetitions. Add weight around your ankle as the exercise becomes easy to complete. Perform on both legs.

Straight Leg Raise: Hip Adduction

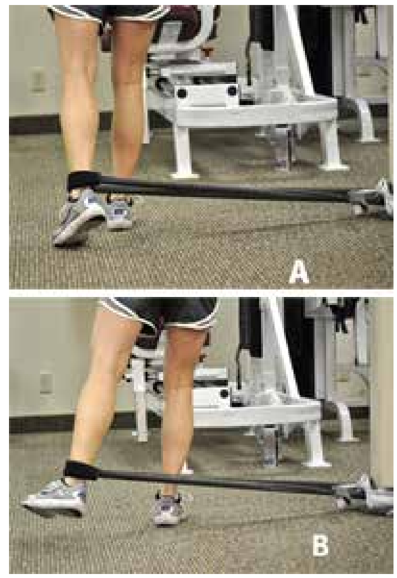
Lie on your side, the one that is painful. Bend the opposite leg and place the foot on the ground in front of the other knee as shown below. Lift your leg toward the ceiling, keeping the knee straight and the toes pointed straight ahead. Hold for 3 seconds, then lower the leg back to the starting position. Add weight around your ankle as the exercise becomes easy to complete. Perform on both legs.

Straight Leg Raises With Resistance Band

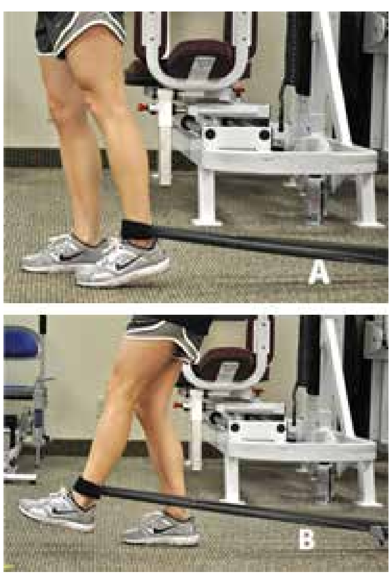
In these exercises, you will perform the same motion that is done during straight leg raises, except you are standing with a resistance band or rubber tubing tied around your ankle/lower leg. Secure the other end of the band or tubing around a heavy object. You will change the position of your feet in order to work the hip adductors, abductors, flexors, and extensors as shown in the photographs below. To help maintain balance, hold onto an object and slightly bend the leg that is not being exercised. Move the foot with the band in the desired direction out as far as possible to ensure the band is tight. Perform 3-5 sets of 30 repetitions, moving the band as fast as possible. Rest for 1 minute between sets. Perform on both legs.



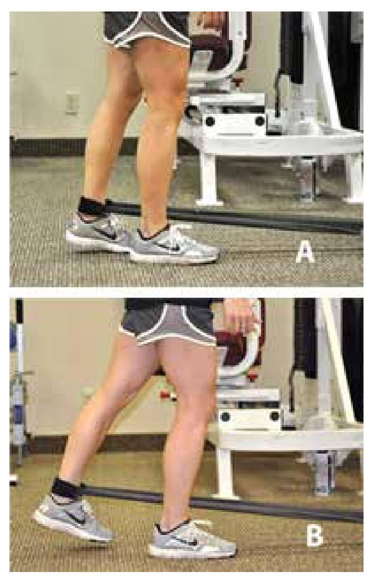
Straight leg raise with resistance band, hip adduction, starting position (A) and ending position (B).



Straight leg raise with resistance band, hip abduction, starting position (A) and ending position (B).



Straight leg raise with resistance band, hip flexion, starting position (A) and ending position (B).



Straight leg raise with resistance band, hip extension, starting position (A) and ending position (B).

Hamstrings Stretch

Sit with your leg lying straight in front of you and bend the opposite knee so that the foot is resting against the inner portion of the other thigh as shown below. Keeping your back straight, slowly lean forward until you feel a stretch in your hamstrings. Hold each stretch for 30 seconds and repeat 5 times on each leg.

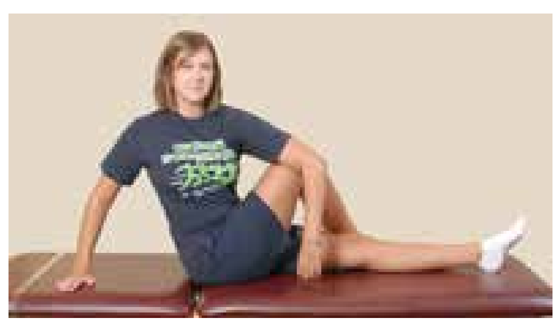
Calf Stretch #1

Sit on a bed or recliner with a foot rest with your back well supported. Take a large towel and roll it up so that is long and thin as shown below. Wrap the middle of the towel around the toes of your leg. While keeping your knee straight, use the towel to bend your toes back toward you until you feel a stretch in your calf muscles. Hold each stretch for 30 seconds and repeat 5 times on each leg.

Calf Stretch #2

Stand with one foot stretched at the back. Keep the back knee bent towards the wall with the heel kept firmly on the ground. The stretch should be felt in the lower aspect of the calf.

Iliotibial Band Stretch



Sit on the floor, bend your right knee, and keep the left knee straight and flat on the floor. Cross the foot of the right side over the left knee as shown below. Place one hand on the floor behind the hips and use the other arm to press the chest toward the knee and foot. This stretch may be done lying on the back to support the spine and neck. Hold each stretch for 30 seconds and repeat 5 times on each leg.

Quadriceps Stretch

From a standing position, grab a foot or ankle and lift it up behind your body. Gently pull the lower leg and foot up, directly behind the upper leg. Do not twist inward or outward. Hold each stretch for 30 seconds and repeat 5 times on each leg.

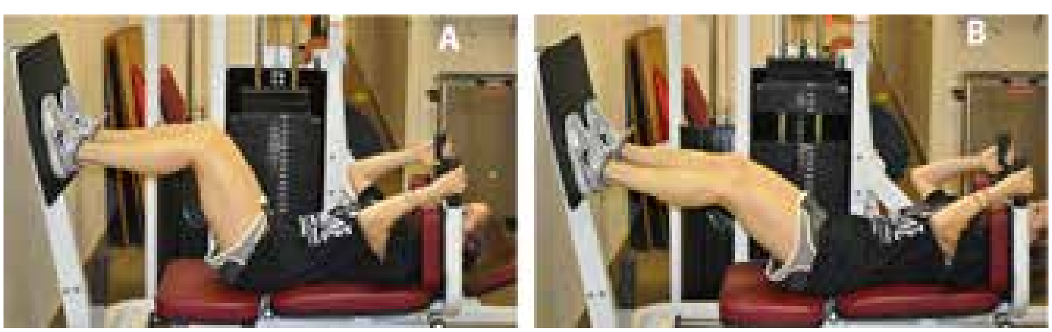
Health, Fitness Club Exercise Machines

Listed below are some simple exercises you may do at a health club to help strengthen the muscles of your legs and hips and improve your cardiac fitness. We strongly believe that you should be under the care of a physical therapist that can guide and progress your exercise program and make sure that the strength training does not cause further knee pain. Always do the stretches shown in the Home Exercise section last in your exercise sessions. If any of these exercises cause pain in your kneecap, stop immediately.

The first time you exercise on the machines described below, have a physical therapist or trainer make sure the machine is adjusted correctly according to your body dimensions. The therapist or trainer should also help to determine the amount of weight to start with initially.

Leg Press

Beginning at 70 degrees, extend your knees slowly to 10 degrees, hold for 1-2 seconds, and slowly return to 70 degrees. Make sure you do this exercise only from 70-10 degrees! Do not press your knees out until they are fully extended, and do not allow your knees to bend all of the way back. Push up through your heels and not your toes. Complete 3 sets of 10 repetitions. Rest for 30 seconds between sets. Gradually increase the amount of weight as you are able.



Hip Abduction/Adduction

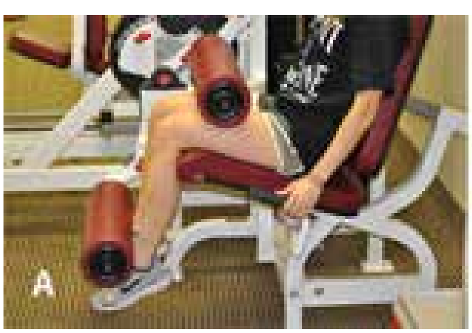
If your fitness facility only has a hip abduction/adduction machine (and not a multi-hip cable machine), then use this to work these muscles. However, if your facility has a multi-hip cable machine, use that instead. On the abduction/adduction machine, be sure to work your legs together, moving gradually and holding the abduction or adduction position for 1-2 seconds before returning to the starting position. Complete 3 sets of 10 repetitions. Rest for 30 seconds between sets. Gradually increase the amount of weight as you are able.

Multi-Hip

A multi-hip machine allows all of the hip muscles to be exercised, including the hip flexors, extensors, abductors, and adductors. Use good posture (keep your back straight) throughout the exercises and hold onto the support bars to ensure you are working just your hip muscles. Complete 3 sets of 10 repetitions in all 4 directions on both sides. Rest for 30 seconds between sets. Gradually increase the amount of weight as you are able.

Knee Extension

Beginning at 90 degrees, extend slowly to 30 degrees, hold for 1-2 seconds, and slowly return to 90 degrees. Make sure you only do this exercise from 90-30 degrees! Do not extend your knees out past 30 degrees, as this will place excessive forces on your kneecap. Complete 3 sets of 10 repetitions. Rest for 30 seconds between sets. Gradually increase the amount of weight as you are able. You may either use both legs to move the bar up and down, use both legs to push the bar up and one leg to bring the bar back down, or use just one leg to move the bar up and down. Perform equal sets on both legs.



Hamstring Curls

Beginning at 0 degrees, flex slowly to 90 degrees, hold for 1-2 seconds, and slowly return to 0 degrees. Make sure you do this exercise from 0-90 degrees! Complete 3 sets of 10 repetitions. Rest for 30 seconds between sets. Gradually increase the amount of weight as you are able. You may either use both legs to move the bar down and up, use both legs to push the bar down and one leg to bring the bar back up, or use just one leg to move the bar down and up. Perform equal sets on both legs.

Upper Body Weight Training

There are many options available for upper body strength training that use either free weights or weight machines. The major upper body muscle groups that should be exercised include the deltoids, pectorals, triceps, biceps, trapezius, rhomboids, and latissimus dorsi. Work with your therapist or a trainer at your fitness facility to develop this aspect of your training program.

Core Training

The "core" is the area of your body that includes your pelvis, abdomen, and lower back. Core strength is crucial to maintain postural support and movement of the trunk. Core stability contributes to athletic performance. In fact, poor core strength may be a contributing factor in MTSS and other lower extremity injuries. The muscles in the abdomen and lower back may be strengthened in many different ways, using either weight machines or exercises such as sit-ups, crunches, bicycle kicks, supine bridges, planks, etc. Work with your therapist or a trainer at your fitness facility to develop this aspect of your training program.

Stationary Bicycle

A stationary bicycle offers a cardiovascular exercise option that may be done provided it does not cause pain. It is important to adjust the seat height correctly so that your knee is just slightly bent when the pedal is in the lowest position. We recommend using low resistance and a level setting initially. If you begin to experience pain during or after riding the bicycle, stop and talk to your therapist.

Cross-Country Ski

This is an excellent machine to use for cardiovascular fitness because it has very little impact on your lower extremity and it also works muscles in your core and upper body. At first, make sure your stride is short, you use the level setting (no incline), and a low resistance. If you begin to experience pain during or after using this machine, stop and talk to your therapist.

Elliptical

This is an excellent machine to use for cardiovascular fitness and has the additional benefits of applying very little impact on your lower extremity while working the muscles in your core and upper body. At first, make you use the level setting (no incline) and a low resistance. If you begin to experience pain during or after using the elliptical, stop and talk to your therapist.

Pool Training

Water Walking and Other Basic Aquatic Exercises

Walk in a pool with the water at least waist-high, forwards and backwards. Gradually increase your speed, the length of your steps, and the distance covered. Make sure you walk with high knee steps, exaggerated from your normal walking appearance. You can also march across the pool. Partial squats and lunges can be done in shallow water in the same manner as they are done on land. There are a variety of exercises that may be done in the pool to increase strength and flexibility, many of which require buoyant or other aquatic equipment. A kick board may be used when walking to increase the amount of resistance. A noodle may be used to support the upper body while doing bicycle kicking. Knee flexion curls may be done with a buoyant circle. Knee extension resistance exercises may be done by placing a noodle under the bottom of a foot and pressing down. In addition, the upper extremity and core muscles may be exercised in a variety of ways in the pool. These including performing arm circles under water, first with the palms up and then with the palms facing down. A buoyant device can be placed between your legs and freestyle swimming done using just your arms. If you have access to a pool and enjoy training in the water, work with your therapist to develop a comprehensive program to be used in conjunction with your other land-based exercises.

Swimming (Straight Ahead Kicking)

If you would like to swim, use straight ahead kicking, as in freestyle and backstroke. Consider adding a mask and snorkel to make breathing easier. You may also use flippers and perform simple flutter kicking to further strengthen your legs.

Acronyms and References

ACL, anterior cruciate ligament
ACSM, American College of Sports Medicine
BMD, bone mineral density
BMI, body mass index
CT, computed tomography
DEXA, dual x-ray absorptiometry scan
IOC, International Olympic Committee
ng/mL, nanograms per milliliter
MRI, magnetic resonance imaging
MTSS, medial tibial stress syndrome
SONK, spontaneous osteonecrosis of the knee

1. Abrams GD, Renstrom PA, Safran MR. Epidemiology of musculoskeletal injury in the tennis player. Br J Sports Med. 2012;46(7):492-498.
2. Agarwal S, Agarwal S, Gupta P, Agarwal PK, Agarwal G, Bansal A. Risk of atypical femoral fracture with long-term use of alendronate (bisphosphonates) : a systemic review of literature. Acta Orthop Belg. 2010;76(5):567-571.
3. Anderson RB, Hunt KJ, McCormick JJ. Management of common sports-related injuries about the foot and ankle. J Am Acad Orthop Surg. 2010;18(9):546-556.
4. Angeline ME, Gee AO, Shindle M, Warren RF, Rodeo SA. The effects of vitamin D deficiency in athletes.

Am J Sports Med. 2013;41(2):461-464.
5. Bartoszewska M, Kamboj M, Patel DR. Vitamin D, muscle function, and exercise performance. Pediatr Clin North Am. 2010;57(3):849-861.
6. Bisson LJ, Kluczynski MA, Hagstrom LS, Marzo JM. A Prospective Study of the Association Between Bone Contusion and Intra-articular Injuries Associated With Acute Anterior Cruciate Ligament Tear. Am J Sports Med. 2013;41(8):1801-1807.
7. Boks SS, Vroegindeweij D, Koes BW, Bernsen RM, Hunink MG, Bierma-Zeinstra SM. MRI follow-up of posttraumatic bone bruises of the knee in general practice. AJR Am J Roentgenol. 2007;189(3):556-562.
8. Bouche RT, Johnson CH. Medial tibial stress syndrome (tibial fasciitis): a proposed pathomechanical model involving fascial traction. J Am Podiatr Med Assoc. 2007;97(1):31-36.
9. Brewer RB, Gregory AJ. Chronic lower leg pain in athletes: a guide for the differential diagnosis, evaluation, and treatment. Sports Health. 2012;4(2):121-127.
10. Cabarrus MC, Ambekar A, Lu Y, Link TM. MRI and CT of insufficiency fractures of the pelvis and the proximal femur. AJR Am J Roentgenol. 2008;191(4):995-1001.
11. Cannell JJ, Hollis BW, Sorenson MB, Taft TN, Anderson JJ. Athletic performance and vitamin D. Med Sci Sports Exerc. 2009;41(5):1102-1110.
12. Cao JJ. Effects of obesity on bone metabolism. J Orthop Surg Res. 2011;6:30.
13. Clarke B. Normal bone anatomy and physiology. Clin J Am Soc Nephrol. 2008;3 Suppl 3:S131-139.
14. Cobb KL, Bachrach LK, Sowers M, et al. The effect of oral contraceptives on bone mass and stress fractures in female runners. Med Sci Sports Exerc. 2007;39(9):1464-1473.
15. Deangelis JP, Spindler KP. Traumatic Bone Bruises in the Athlete's Knee. Sports Health. 2010;2(5):398-402.
16. Dixon S, Newton J, Teh J. Stress fractures in the young athlete: a pictorial review. Curr Probl Diagn Radiol. 2011;40(1):29-44.
17. Ducher G, Turner AI, Kukuljan S, et al. Obstacles in the optimization of bone health outcomes in the female athlete triad. Sports Med. 2011;41(7):587-607.
18. Endele D, Jung C, Bauer G, Mauch F. Value of MRI in diagnosing injuries after ankle sprains in children. Foot Ankle Int. 2012;33(12):1063-1068.
19. Fazzalari NL. Bone fracture and bone fracture repair. Osteoporos Int. 2011;22(6):2003-2006.
20. Franklyn M, Oakes B. Tibial stress injuries: aetiology, classification, biomechanics and the failure of bone. In: Zaslav KR, ed. An international perspective on topics in sports medicine and sports injury: InTech; 2012.
21. Frobell RB. Change in cartilage thickness, posttraumatic bone marrow lesions, and joint fluid volumes after acute ACL disruption: a two-year prospective MRI study of sixty-one subjects. J Bone Joint Surg Am. 2011;93(12):1096-1103.
22. Furia JP, Rompe JD, Cacchio A, Maffulli N. Shock wave therapy as a treatment of nonunions, avascular necrosis, and delayed healing of stress fractures. Foot Ankle Clin. 2010;15(4):651-662.
23. Gaeta M, Minutoli F, Scribano E, et al. CT and MR imaging findings in athletes with early tibial stress injuries: comparison with bone scintigraphy findings and emphasis on cortical abnormalities. Radiology. 2005;235(2):553-561.
24. Geeslin AG, Laprade RF. Location of Bone Bruises and Other Osseous Injuries Associated With Acute Grade III Isolated and Combined Posterolateral Knee Injuries. Am J Sports Med. 2010;38(12):2502-2508.
25. Geijer M, Dunker D, Collin D, Gothlin JH. Bone bruise, lipohemarthrosis, and joint effusion in CT of non-displaced hip fracture. Acta Radiol. 2012;53(2):197-202.
26. Goud A, Khurana B, Chiodo C, Weissman BN. Women's musculoskeletal foot conditions exacerbated by shoe wear: an imaging perspective. Am J Orthop (Belle Mead NJ). 2011;40(4):183-191.
27. Holick MF. Vitamin D deficiency. N Engl J Med. 2007;357(3):266-281.
28. Jarraya M, Hayashi D, Roemer FW, et al. Radiographically occult and subtle fractures: a pictorial review. Radiol Res Pract. 2013;2013:370169.
29. Jones GL. Upper extremity stress fractures. Clin Sports Med. 2006;25(1):159-174, xi.

30. Kaeding CC, Najarian RG. Stress fractures: classification and management. Phys Sportsmed. 2010;38(3):45-54.
31. Kelsey JL, Bachrach LK, Procter-Gray E, et al. Risk factors for stress fracture among young female cross-country runners. Med Sci Sports Exerc. 2007;39(9):1457-1463.
32. Kovacevic D, Mariscalco M, Goodwin RC. Injuries about the hip in the adolescent athlete. Sports Med Arthrosc. 2011;19(1):64-74.
33. Lappe J, Cullen D, Haynatzki G, Recker R, Ahlf R, Thompson K. Calcium and vitamin D supplementation decreases incidence of stress fractures in female navy recruits. J Bone Miner Res. 2008;23(5):741-749.
34. Liong SY, Whitehouse RW. Lower extremity and pelvic stress fractures in athletes. Br J Radiol. 2012;85(1016):1148-1156.
35. Longo UG, Loppini M, Romeo G, van Dijk CN, Maffulli N, Denaro V. Bone bruises associated with acute ankle ligament injury: do they need treatment? Knee Surg Sports Traumatol Arthrosc. 2013;21(6):1261-1268.
36. Mandalia V, Henson JH. Traumatic bone bruising--a review article. Eur J Radiol. 2008;67(1):54-61.
37. McCabe MP, Smyth MP, Richardson DR. Current concept review: vitamin D and stress fractures. Foot Ankle Int. 2012;33(6):526-533.
38. McCormick F, Nwachukwu BU, Provencher MT. Stress fractures in runners. Clin Sports Med. 2012;31(2):291-306.
39. McDonnell LK, Hume PA, Nolte V. Rib stress fractures among rowers: definition, epidemiology, mechanisms, risk factors and effectiveness of injury prevention strategies. Sports Med. 2011;41(11):883-901.
40. Miller T, Kaeding CC, Flanigan D. The classification systems of stress fractures: a systematic review. Phys Sportsmed. 2011;39(1):93-100.
41. Moen MH, Bongers T, Bakker EW, et al. Risk factors and prognostic indicators for medial tibial stress syndrome. Scand J Med Sci Sports. 2012;22(1):34-39.
42. Moen MH, Holtslag L, Bakker E, et al. The treatment of medial tibial stress syndrome in athletes; a randomized clinical trial. Sports Med Arthrosc Rehabil Ther Technol. 2012;4:12.
43. Moen MH, Rayer S, Schipper M, et al. Shockwave treatment for medial tibial stress syndrome in athletes; a prospective controlled study. Br J Sports Med. 2012;46(4):253-257.
44. Moen MH, Tol JL, Weir A, Steunebrink M, De Winter TC. Medial tibial stress syndrome: a critical review. Sports Med. 2009;39(7):523-546.
45. Mont MA, Marker DR, Zywiel MG, Carrino JA. Osteonecrosis of the knee and related conditions. J Am Acad Orthop Surg. 2011;19(8):482-494.
46. Nattiv A, Loucks AB, Manore MM, Sanborn CF, Sundgot-Borgen J, Warren MP. American College of Sports Medicine position stand. The female athlete triad. Med Sci Sports Exerc. 2007;39(10):1867-1882.
47. Navas A, Kassarjian A. Bone marrow changes in stress injuries. Semin Musculoskelet Radiol. 2011;15(3):183-197.
48. Nieves JW, Melsop K, Curtis M, et al. Nutritional factors that influence change in bone density and stress fracture risk among young female cross-country runners. PM R. 2010;2(8):740-750; quiz 794.
49. Paakkala A, Sillanpaa P, Huhtala H, Paakkala T, Maenpaa H. Bone bruise in acute traumatic patellar dislocation: volumetric magnetic resonance imaging analysis with follow-up mean of 12 months. Skeletal Radiol. 2010;39(7):675-682.
50. Pantano KJ. Strategies used by physical therapists in the U.S. for treatment and prevention of the female athlete triad. Phys Ther Sport. 2009;10(1):3-11.
51. Papanek PE. The female athlete triad: an emerging role for physical therapy. J Orthop Sports Phys Ther. 2003;33(10):594-614.
52. Pape D, Filardo G, Kon E, van Dijk CN, Madry H. Disease-specific clinical problems associated with the subchondral bone. Knee Surg Sports Traumatol Arthrosc. 2010;18(4):448-462.
53. Patel DS, Roth M, Kapil N. Stress fractures: diagnosis, treatment, and prevention. Am Fam Physician. 2011;83(1):39-46.

54. Pegrum J, Crisp T, Padhiar N. Diagnosis and management of bone stress injuries of the lower limb in athletes. BMJ. 2012;344:e2511.
55. Porrino JA, Jr., Kohl CA, Taljanovic M, Rogers LF. Diagnosis of proximal femoral insufficiency fractures in patients receiving bisphosphonate therapy. AJR Am J Roentgenol. 2010;194(4):1061-1064.
56. Potter HG, Jain SK, Ma Y, Black BR, Fung S, Lyman S. Cartilage Injury After Acute, Isolated Anterior Cruciate Ligament Tear: Immediate and Longitudinal Effect With Clinical/MRI Follow-up. Am J Sports Med. 2012;40(2):276-285.
57. Rauck RC, LaMont LE, Doyle SM. Pediatric upper extremity stress injuries. Curr Opin Pediatr. 2013;25(1):40-45.
58. Reshef N, Guelich DR. Medial tibial stress syndrome. Clin Sports Med. 2012;31(2):273-290.
59. Roemer FW, Frobell R, Hunter DJ, et al. MRI-detected subchondral bone marrow signal alterations of the knee joint: terminology, imaging appearance, relevance and radiological differential diagnosis. Osteoarthritis Cartilage. 2009;17(9):1115-1131.
60. Rosen CJ. Clinical practice. Vitamin D insufficiency. N Engl J Med. 2011;364(3):248-254.
61. Ross AC, Taylor CL, Yaktine AL, Del Valle HB. Dietary reference intakes for calcium and vitamin D. Washington, DC: National Academy of Sciencies. Institute of Medicine; 2011.
62. Royer M, Thomas T, Cesini J, Legrand E. Stress fractures in 2011: practical approach. Joint Bone Spine. 2012;79 Suppl 2:S86-90.
63. Schneiders AG, Sullivan SJ, Hendrick PA, et al. The ability of clinical tests to diagnose stress fractures: a systematic review and meta-analysis. J Orthop Sports Phys Ther. 2012;42(9):760-771.
64. Scofield KL, Hecht S. Bone health in endurance athletes: runners, cyclists, and swimmers. Curr Sports Med Rep. 2012;11(6):328-334.
65. Shindle MK, Endo Y, Warren RF, et al. Stress fractures about the tibia, foot, and ankle. J Am Acad Orthop Surg. 2012;20(3):167-176.
66. Smith PT. Discrepancies in clinical definitions of stress fractures: implications for the United States Army. Mil Med. 2011;176(1):60-66.
67. Spiker AM, Dixit S, Cosgarea AJ. Triathlon: running injuries. Sports Med Arthrosc. 2012;20(4):206-213.
68. Stickley CD, Hetzler RK, Kimura IF, Lozanoff S. Crural fascia and muscle origins related to medial tibial stress syndrome symptom location. Med Sci Sports Exerc. 2009;41(11):1991-1996.
69. Strauss EJ, Kang R, Bush-Joseph C, Bach BR, Jr. The diagnosis and management of spontaneous and post-arthroscopy osteonecrosis of the knee. Bull NYU Hosp Jt Dis. 2011;69(4):320-330.
70. Tenforde AS, Sayres LC, Sainani KL, Fredericson M. Evaluating the relationship of calcium and vitamin D in the prevention of stress fracture injuries in the young athlete: a review of the literature. PM R. 2010;2(10):945-949.
71. Thein-Nissenbaum JM, Carr KE. Female athlete triad syndrome in the high school athlete. Phys Ther Sport. 2011;12(3):108-116.
72. Verrelst R, Willems TM, Clercq DD, Roosen P, Goossens L, Witvrouw E. The role of hip abductor and external rotator muscle strength in the development of exertional medial tibial pain: a prospective study. Br J Sports Med. 2013.
73. Vescovi JD, Jamal SA, De Souza MJ. Strategies to reverse bone loss in women with functional hypothalamic amenorrhea: a systematic review of the literature. Osteoporos Int. 2008;19(4):465-478.
74. Ward KA, Das G, Berry JL, et al. Vitamin D status and muscle function in post-menarchal adolescent girls. J Clin Endocrinol Metab. 2009;94(2):559-563.
75. Wentz L, Liu PY, Haymes E, Ilich JZ. Females have a greater incidence of stress fractures than males in both military and athletic populations: a systemic review. Mil Med. 2011;176(4):420-430.
76. Yao L, Stanczak J, Boutin RD. Presumptive subarticular stress reactions of the knee: MRI detection and association with meniscal tear patterns. Skeletal Radiol. 2004;33(5):260-264.
77. Yeung SS, Yeung EW, Gillespie LD. Interventions for preventing lower limb soft-tissue running injuries.

Cochrane Database Syst Rev. 2011(7):CD001256.
78. Yoon JP, Chang CB, Yoo JH, et al. Correlation of magnetic resonance imaging findings with the chronicity of an anterior cruciate ligament tear. J Bone Joint Surg Am. 2010;92(2):353-360.
79. Yoon KH, Yoo JH, Kim KI. Bone contusion and associated meniscal and medial collateral ligament injury in patients with anterior cruciate ligament rupture. J Bone Joint Surg Am. 2011;93A(16):1510-1518.
80. Zadpoor AA, Nikooyan AA. The relationship between lower-extremity stress fractures and the ground reaction force: a systematic review. Clin Biomech (Bristol, Avon). 2011;26(1):23-28.